THE EFFECT OF

INITIAL AND BACK PRESSURES

UPON THE

WATER RATE OF A SIMPLE STEAM ENGINE

BY

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B. S., UNIVERSITY OF ILLINOIS, 1905

THESIS

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE

DEGREE OF

MECHANICAL ENGINEER

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1916

UNIVERSITY OF ILLINOIS

THE GRADUATE SCHOOL

May 3 1916

I HEREBY RECOMMEND THAT THE THESIS PREPARED BY

Harry Frederick Godeke

ENTITLED The Effect of Initial and Back Pressures upon the Water Rate of a Simple Steam Engine.

BE ACCEPTED AS FULFILLING THIS PART ON THE REQUIREMENTS FOR THE PROFESSIONAL DEGREE OF Mechanical Engineer.

C. R. Richards

Head of Department of Mechanical Engineering

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I. INTRODUCTION.

Steam engines are often sold with a gurantee to give a certain performance when operating under certain conditions of initial and back pressures. Generally these conditions can not be attained and maintained constant throughout the test. A correction of the results must then be made on some basis so that these corrected results shall be comparable with the guarantee made. These corrections are sometimes made by means of curves taken from similar machines operating under like conditions and sometimes by means of rational formulas which are supposed to hold over the limit of variation of conditions,obtained on the test, from those specified in the guarantee. In no case is it assumed that this correction shall hold over any large range.

II. OBJECT.

The purpose in view in starting this thesis was to find out from an extensive series of tests upon a simple engine whether or not some rational correction, founded upon some such basis as available heat drop, could be made to apply over any large variation of initial and back pressures or if it could be considered as accurate over even a medium range. In case such a rational correction was not found to be applicable the alternate object was to draw a set of curves, showing the economy of the engine under the different conditions of load, initial and back pressures, which might be considered as a criterion for correction for similar conditions obtained with similar engines.

III. APPARATUS TESTED.

The machine upon which these tests were conducted was an 8" x 18", simple, horizontal, double-acting, Corliss engine, built by the Murray Iron Works of Burlington, Ia. This engine had been used for air and steam mixtures so that it was in rather poor condition. Preparatory to the tests the valves were ground in and the engine put in good order. After this, however, it required quite a lot of running to put it in shape so that the results could be considered as characteristic for the engine, or, in other words, so that the results from one test could be duplicated by another test under similar operating conditions.

IV. TESTING APPARATUS.

The engine was fitted with a band prony brake of special design capable of taking care of the maximum load of the engine.

The reducing motion used was a special design consisting of a side shaft with a spiral wedge groove engaging a wedge-shaped pin extending from the cross head. Upon this shaft were two sectors each operating an indicator.

Two outside spring Crosby indicators were used with 80 lb. springs and 1 1/2 inch drums.

A throttling calorimeter, with a mercury thermometer, was used to determine the quality of the steam supplied to the engine.

A 0-150 lb. test gage connected near the throttle of the engine was used to measure the initial pressure and a compound gage attached to the exhaust pipe just below the engine cylinder was used to get the back pressure.

To determine the weight of steam used, a Worthington condenser of 360 sq. ft. cooling surface was used, the steam condensed being weighed in a tank sufficiently large to hold the steam condensed in one hour. It might be well to add here that the condenser was out of proportion for the engine but that its use was necessary, due to the small condenser installed with the engine not having an air pump.

V. METHOD OF CONDUCTING TESTS.

One hour tests were run, data being taken every ten minutes. Three initial pressures were used, 120, 100, and 80 lb. gage. With each of these pressures six different back pressures were used, 20", 10", 0, 5 lb., 10 lb., and 15 lb. Initial pressure was kept constant by means of a gate valve in the main at the west entrance of the laboratory, the length of main acting as a reservoir for equalizing the pressure.

Back pressure was kept constant by means of a valve in the exhaust pipe near the condenser, the length of the pipe to this point acting as a reservoir for the exhaust steam. By careful adjustment of these valves close regulation of pressures was maintained.

Beginning with 5 brake horse power, the load was increased by approximately 5 b.h.p. increments for each of the conditions of initial and back pressures; in each case the load being carried to the maximum load the engine would pull with the existing conditions. For every change of load the governor rods were adjusted for proper distribution of load and the engine was run long enough to get conditons constant before the test was started.

The tare of the brake (42 lb.) was determined by turning the engine forward and backward before starting the tests. The revolutions per minute were obtained from a Veeder continuous counter.

VI. CALIBRATION OF APPARATUS.

All apparatus used was calibrated before the tests. The indicator No. 1080, used on the head end, had an average true value for the spring of 79.6 lb., while the one for the crank end No. 1083 had an average true value of 78 lb. The gages were adjusted until the error was within the error of observation. The thermometer used for the calorimeter was correct within limits of observation. The scales used for the brake were sensitive to within less than a quarter of a pound.

VII. LOG OF TEST.

Inasmuch as conditions were kept constant during the test no log is given, but all average data are to be found in the result sheets.

VIII. SAMPLE CALCULATIONS.

The following sample calculations apply to test number 1, and are characteristic for all the tests. Steam table values are gotten from Marks and Davis Steam Tables, values for heat content being taken from the Mollier Diagram accompanying the tables.

Item No. 3. Atmospheric pressure = Barometer reading x .491 = 29.55 x .491 = 14.50 lb. per sq. in.

Item No. 5. Absolute steam pressure = Gage reading + Atmospheric pressure = 120.7 + 14.5 = 135.2 lb. per sq. in.

Item No. 7. (Barometer reading - Exhaust gage reading) x .491 = (29.55 - 20.03) x .491 = 4.67.

Item No. 9. Quality of steam, from Mollier chart = .986.

Item No. 13. Brake horse power = $\frac{2\pi rnw}{33000}$ = Knw.

$$K = \frac{2 \times \pi \times 5.25}{33000} = .001$$

$$\text{b. h. p.} = .001 \times 102.4 \times 342 = 35.03$$

Item 16. Indicated horse power, Head end = $\frac{plan}{33000}$ = cpn

$$c = \frac{1.5 \times 50.27}{33000} = .002273.$$

$$\text{i. h. p.} = .002273 \times 82.3 \times 102.4 = 19.26$$

Item 17. Indicated horse power, Crank end = $\frac{p'la'n}{33000}$ = c'pn

$$c' = \frac{1.5 \times (50.27 - 2.76)}{33000} = .00216$$

$$\text{i. h. p.} = .00216 \times 81.3 \times 102.4 = 17.98$$

Item 18. I. h. p. total = i. h. p. (H. E.) + i. h. p. (C. E.) = 19.26 + 17.98 = 37.24.

Items 20 and 21. Condensate per h. p. hr. = Steam used per hr. ÷ total h. p. = 915 ÷ 37.24 = 24.56 lb. per i. h. p. hr., or 915 ÷ 35.03 = 26.11 lb. per b. h. p. hr.

Items 22 and 23. Dry steam per h. p. hr. (water rate) = Condensate per h. p. hr. x quality.

24.56 x .986 = 24.22 lb. per i. h. p. hr.

or 26.11 x .986 = 25.74 lb. per b. h. p. hr.

Item 24. Heat content of steam -- gotten from Mollier chart = 1179.

Item 25. Heat content of steam after adiabatic expansion to back pressure -- gotten from Mollier chart.

Item 26. Available heat drop -- gotten from items (24) and

(25) = 1179 - 952 = 227.

Item 29. Mechanical efficiency = $\frac{\text{b. h. p.}}{\text{i. h. p.}} = \frac{35.03}{37.24} = .941$ or 94.1%.

Item 30. Thermal efficiency = Heat utilized per lb. steam ÷ heat supplied per lb. steam.

Heat utilized per lb. steam = $\frac{2546}{24.56} = 103.7$ B. t. u.

Heat supplied per lb. steam = 1179 - 127 = 1052.

Th. effic. = $\frac{103.7}{1052} = .0986$ or 9.86%.

Item 31. Potential efficiency = Heat utilized by actual engine per lb. steam as compared to that utilized by the theoretical Rankine engine operating under similar conditions = $\frac{103.7}{227} = .457$ or 45.7%.

Item 32. Ratio of expansion = Ratio of cylinder volume including clearance to volume filled with steam at cut-off. Here the actual cut-off was located from the diagram and the "nominal" cut-off located on the initial pressure line. Two characteristic diagrams for each test for each end of the cylinder were taken, the average ratio of expansion for each end of the cylinder and from these the average value for both ends was computed.

Length of diagram = 3.84 in.

Equivalent length including clearance, H. E. = 4.05 in., C. E. = 4.06 in.

Length at cut-off, including clearance, H. E. = 1.38 in., C. E. = 1.34 in.

Pressure at cut-off, H. E. = 105.1 lb., C. E. = 107.7 lb.

Absolute pressures = 119.6 lb. and 122.2 lb.

$\frac{119.6 \times 1.38}{134.5} = 1.227$ for nominal cut-off on head end.

$\frac{122.2 \times 134}{134.5} = 1.217$ for nominal cut-off on crank end.

r for head end = $\frac{4.05}{1.227} = 3.3$

r for crank end = $\frac{4.06}{1.217} = 3.34$

Av. value of r for both ends = 3.32

The Effect of Initial and Back Pressures upon the
Water Rate of a Simple Steam Engine.

Results of Tests. Table No.1 – Initial Pressure-120 lb.

H.F. Godeke

No.	Name of Item	Trial Number 1	2	3	4	6	7	8	9	10	15	16
1	Duration of trial -hr.	1	1	1	1	1	1	1	1	1	1	1
2	Barometer -in. of Hg.	29.55	29.30	29.28	29.25	29.20	29.16	29.12	29.16	29.20	29.21	29.40
3	Atmospheric pressure -#/sq.in.	14.50	14.38	14.37	14.36	14.33	14.31	14.29	14.31	14.33	14.34	14.43
4	Steam pressure -#/sq.in.	120.7	120.1	120.4	119.9	120.1	120.0	120.5	120.3	120.4	120.1	119.9
5	Abs. Steam pressure -#/sq.in.	135.2	134.5	134.8	134.3	134.4	134.3	134.8	134.6	134.7	134.4	134.3
6	Exhaust pressure or vacuum.	20.03"	20.00"	10.00"	0.00	20.00"	10.00"	0.00	4.97#	10.00#	15.03#	20.00"
7	Abs. exhaust pressure -#/sq.in.	4.67	4.56	9.46	14.36	4.51	9.40	14.29	19.28	24.33	29.37	4.61
8	Calorimeter temperature -deg.F.	274.4	274.5	276.5	266.7	267.3	280.4	280.9	280.5	280.3	264.6	266.9
9	Quality of steam	.986	.986	.987	.981	.982	.989	.989	.989	.989	.981	.982
10	Room temperature -deg.F.	69	65	65.5	67	65	72	68	68.5	69	61	63.5
11	Rev. per min.	102.4	102.6	102.4	102.3	104	103.7	103.6	102.6	102.2	102.9	106.2
12	Net weight on brake scales -lb.	342	291	292	292	242	242	242	242	242	242	194
13	Brake horsepower	35.03	29.67	29.91	29.89	25.16	25.10	25.07	24.83	24.73	24.90	20.60
14	Mean effective pressure - H.E.	82.3	70.5	69.83	72.33	58.45	55.97	57.50	55.55	57.00	56.17	46.20
15	Mean effective pressure - C.E.	81.3	70.9	70.10	65.80	60.36	61.38	57.70	58.72	56.70	57.73	49.21
16	Indicated horse power - H.E.	19.26	16.50	16.35	16.90	13.90	13.26	13.60	13.01	13.31	13.19	11.21
17	Indicated horse power - C.E.	17.98	15.72	15.50	14.55	13.55	13.75	12.90	13.01	12.52	12.90	11.29
18	Indicated horse power - Total	37.24	32.22	31.85	31.45	27.45	27.01	26.50	26.02	25.83	26.09	22.50
19	Condensate per hr. -lb.	915	781	809	876.5	662.5	690	735.5	766.5	804	866	555
20	Condensate per i.h.p.hr. -lb.	24.56	24.24	25.40	27.87	24.14	25.53	27.80	29.45	31.12	33.20	24.67
21	Condensate per b.h.p.hr. -lb.	26.11	26.34	27.04	29.34	26.35	27.49	29.40	30.89	32.50	34.78	26.95
22	Dry steam per i.h.p.hr. -lb.	24.22	23.90	25.07	27.34	23.71	25.25	27.49	29.13	30.78	32.57	24.23
23	Dry steam per b.h.p.hr. -lb.	25.74	25.87	26.69	28.78	25.88	27.19	29.08	30.55	32.14	34.12	26.47
24	Heat content of steam (i_1) B.t.u.	1179	1179	1180	1175	1176	1182	1182	1182	1162	1175	1176
25	Same after adiab. exp. to p_2 (i_2) B.t.u.	952	950	992.5	1015	948	994	1020	1039	1055	1061.5	950
26	$i_1 - i_2$ B.t.u.	227	229	187.5	160	228	188	162	143	127	113.5	226
27	Sensible heat at exh. press. (i_2') B.t.u.	127.3	126.3	158.5	178.8	125.8	158.2	179.6	194.1	206.9	217.5	126.7
28	$i_1 - i_2'$ B.t.u.	1052	1053	1022	996	1050	1024	1002	988	975	958	1049
29	Mechanical efficiency -%	94.1	92.0	94.1	95	91.7	92.9	94.6	95.4	95.8	95.5	91.6
30	Thermal efficiency -%	9.86	9.97	9.81	9.18	10.03	9.74	9.13	8.75	8.39	8.00	9.84
31	Potential efficiency -%	45.7	45.9	53.4	57.1	46.2	53.0	56.5	60.4	64.4	67.5	45.7
32	Ratio of expansion	3.32	4.31	3.83	3.40	5.61	4.96	4.49	3.94	3.54	3.15	7.42

No.	Name of Item	19	18	21	22	23	33	34	37	35	87	42
1	Duration of trial -hr.	1	1	1	1	1	1	1	1	1	1	1
2	Barometer -in. of Hg.	29.46	29.10	29.05	29.10	29.13	29.83	29.80	29.02	29.80	28.89	29.72
3	Atmospheric pressure -#/sq.in.	14.46	14.29	14.26	14.28	14.30	14.64	14.63	14.25	14.65	14.24	14.59
4	Steam pressure -#/sq.in.	120.0	119.8	120.0	120.0	119.3	119.9	120.3	120.0	120.2	120.0	120.0
5	Abs. Steam pressure -#/sq.in.	134.5	134.1	134.3	134.3	133.6	134.5	134.9	134.3	134.8	134.2	134.6
6	Exhaust pressure or vacuum.	10.00"	0.00	5.00#	10.00#	15.00#	20.00"	10.00"	0.00	5.00#	10.00#	15.00#
7	Abs. exhaust pressure -#/sq.in.	9.55	14.28	19.26	24.28	29.30	4.82	9.72	14.25	19.63	24.24	29.59
8	Calorimeter temperature -deg.F.	265.0	279.0	276.1	280.6	280.1	271.9	275.6	278.7	268.9	262.9	280.1
9	Quality of steam	.981	.988	.987	.989	.988	.985	.987	.988	.983	.981	.989
10	Room temperature -deg.F.	62.	65	67	71	73	71.5	72.5	75	64.5	81.5	70
11	Rev. per min.	105.7	104.5	104.8	104.2	104	107.2	106.7	105.9	105.8	105.7	104.2
12	Net weight on brake scales -lb.	194	194	194	194	194	144	144	144	144	144	144
13	Brake horsepower	20.50	20.27	20.33	20.22	20.17	15.44	15.37	15.25	15.23	15.22	15.00
14	Mean effective pressure - H.E.	46.85	46.50	45.80	44.78	45.60	34.62	34.42	34.41	34.63	34.00	33.17
15	Mean effective pressure - C.E.	49.60	46.98	47.80	47.80	46.80	37.86	37.47	36.66	35.65	36.47	36.06
16	Indicated horse power - H.E.	11.31	11.10	10.97	10.67	10.85	8.48	8.40	8.33	8.38	8.22	7.90
17	Indicated horse power - C.E.	11.32	10.60	10.83	10.76	10.51	8.77	8.64	8.38	8.22	8.32	8.12
18	Indicated horse power - Total	22.63	21.70	21.80	21.43	21.36	17.25	17.04	16.71	16.60	16.54	16.02
19	Condensate per hr. -lb.	594	622.5	660.5	691.5	720	456	479.5	506.5	536.5	571	588.5
20	Condensate per i.h.p.hr. -lb.	26.15	28.70	30.30	32.25	33.73	26.43	28.15	30.32	32.32	34.52	36.74
21	Condensate per b.h.p.hr. -lb.	28.98	30.77	32.50	34.19	35.72	29.54	31.20	33.20	35.20	37.53	39.25
22	Dry steam per i.h.p.hr. -lb.	25.65	28.36	29.91	31.90	33.33	26.03	27.78	29.96	31.77	33.86	36.33
23	Dry steam per b.h.p.hr. -lb.	28.43	30.40	32.08	33.81	35.29	29.10	30.79	32.80	34.60	33.15	38.82
24	Heat content of steam (i_1) B.t.u.	1175	1181	1180	1182	1181	1178	1180	1181	1176.5	1175	1181.5
25	Same after adiab. exp. to p_2 (i_2) B.t.u.	990	1019	1037	1054.5	1066	953	994.5	1020	1035.5	1049.5	1067.5
26	$i_1 - i_2$ B.t.u.	185	162	143	127.5	115	225	185.5	161	141	125.5	114.
27	Sensible heat at exh. press. (i_2') B.t.u.	159	179.6	194.1	206.8	217.4	128.6	159.8	178.4	195.1	206.7	218
28	$i_1 - i_2'$ B.t.u.	1016	1001	986	975	964	1049	1020	1003	981	968	963
29	Mechanical efficiency -%	90.6	93.4	93.2	94.4	94.5	89.5	90.2	91.3	91.8	92.0	93.7
30	Thermal efficiency -%	9.58	8.86	8.53	8.10	7.83	9.19	8.86	8.37	8.03	7.62	7.19
31	Potential efficiency -%	52.6	54.7	58.8	61.9	65.6	42.8	48.7	52.1	55.8	58.8	42.1
32	Ratio of expansion	6.59	5.77	5.15	4.76	4.00	11.33	10.02	8.31	7.26	6.06	5.40

No.	Name of Item	49	54	53	50	51	52	106	107	92	70	71	72
1	Duration of trial -hr.	1	1	1	1	1	1	1	1	1	1	1	1
2	Barometer -in. of Hg.	29.87	29.46	28.99	29.62	29.56	29.43	29.42	29.40	29.03	29.22	29.12	29.11
3	Atmospheric pressure -#/sq.in.	14.66	14.46	14.25	14.54	14.51	14.45	14.44	14.43	14.25	14.34	14.29	14.29
4	Steam pressure -#/sq.in.	120.0	120.0	120.1	119.9	120	120	120	120	120	120	120	120.1
5	Abs. Steam pressure -#/sq.in.	134.7	134.5	134.4	134.4	134.5	134.5	134.4	134.4	134.3	134.3	134.3	134.4
6	Exhaust pressure or vacuum.	20.00"	10.00"	0.00	5.00#	10.00#	15.00#	20.00"	10.00"	0.00	5.00#	10.00#	15.00#
7	Abs. exhaust pressure -#/sq.in.	4.84	9.55	14.25	19.54	24.51	29.45	4.62	9.52	14.25	19.34	24.29	29.29
8	Calorimeter temperature -deg.F.	281.1	270.1	280.7	278.3	279.9	278.6	281	282.3	274.7	278.7	274.9	275.1
9	Quality of steam	.989	.983	.989	.988	.988	.988	.989	.990	.987	.988	.986	.987
10	Room temperature -deg.F.	70	71	76	73	71.5	72	68	68.5	65	70	70	71
11	Rev. per min.	108.8	107.7	107.2	107	105.9	105.2	109.8	109.5	109.6	108.5	107.8	107
12	Net weight on brake scales -lb.	95	95	95	95	95	95	47	47	47	47	47	47
13	Brake horsepower	10.33	10.23	10.18	10.16	10.06	10.00	5.16	5.15	5.15	5.10	5.06	5.03
14	Mean effective pressure - H.E.	22.60	22.18	22.75	21.35	21.57	21.56	11.40	12.02	12.44	12.02	11.40	11.82
15	Mean effective pressure - C.E.	25.32	25.52	25.06	25.73	24.50	25.73	14.18	13.78	13.77	13.37	14.50	13.57
16	Indicated horse power - H.E.	5.67	5.46	5.52	5.22	5.22	5.18	2.86	3.01	3.11	2.98	2.81	2.89
17	Indicated horse power - C.E.	5.95	5.94	5.80	5.95	5.60	5.84	3.36	3.17	3.26	3.13	3.38	3.14
18	Indicated horse power - Total	11.62	11.40	11.32	11.17	10.82	11.02	6.22	6.18	6.37	6.11	6.19	6.03
19	Condensate per hr. -lb.	370	385.5	404	429	449	481.5	272	294.5	319	341.5	377	404.5
20	Condensate per i.h.p.hr. -lb.	31.84	33.83	35.70	38.40	41.50	43.70	43.72	47.65	50.08	55.9	60.9	67.1
21	Condensate per b.h.p.hr. -lb.	35.80	37.69	39.70	42.23	44.63	48.15	52.70	57.18	61.95	66.95	74.50	80.40
22	Dry steam per i.h.p.hr. -lb.	31.49	33.25	35.31	37.94	41.00	43.18	43.28	47.17	49.43	55.23	59.05	66.23
23	Dry steam per b.h.p.hr. -lb.	35.41	37.05	39.26	41.72	44.10	47.57	52.12	56.61	61.15	66.15	73.45	79.36
24	Heat content of steam (i_1) B.t.u.	1182	1177	1182	1181	1181	1181	1182	1182.5	1180	1181	1179.5	1179.5
25	Same after adiab. exp. to p_2 (i_2) B.t.u.	956	990.5	1019.5	1039	1054.5	1067	953	994.5	1018	1038	1052.5	1066
26	$i_1 - i_2$ B.t.u.	226	186.5	162.5	142	126.5	114	219	188	162	143	127	113.5
27	Sensible heat at exh. press. (i_2') B.t.u.	128.8	159	178.4	194.8	207.3	217.6	126.8	158.5	178.4	194.3	206.8	217.4
28	$i_1 - i_2'$ B.t.u.	1053	1018	1004	986	974	963	1055.2	1023.7	1002	987	973	962
29	Mechanical efficiency -%	88.9	89.6	89.9	91.0	93.1	90.7	83.0	83.3	80.8	83.5	81.8	84.9
30	Thermal efficiency -%	7.59	7.39	7.10	6.72	6.30	6.05	5.52	5.22	5.07	4.62	4.13	3.94
31	Potential efficiency -%	35.4	40.3	43.9	46.6	48.5	51.1	26.6	28.4	26.9	31.9	31.6	33.4
32	Ratio of expansion	18.73	15.33	12.26	10.12	8.47	7.48	34.35	26.06	20.48	15.66	12.38	10.43

The Effect of Initial and Back Pressures upon the Water Rate of a Simple Steam Engine.

Results of Tests. Table No. 2 - Initial Pressure-100 lb.

H.F. Godeke

No.	Name of Item.	Trial Number 5	11	12	14	86	28	29	30	31	32	104	48	46	45
1	Duration of trial -hr.	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Barometer -In. of Hg.	29.22	29.21	29.38	29.27	29.58	29.55	29.52	29.50	29.47	29.45	29.35	29.87	29.85	29.86
3	Atmospheric pressure -#/sq.in.	14.34	14.34	14.42	14.37	14.52	14.50	14.49	14.48	14.47	14.46	14.41	14.66	14.65	14.65
4	Steam pressure -#/sq.in.	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.4	100.1	100.3	100.0	100.0	100.1	100.1
5	Abs. steam pressure -#sq.in.	114.5	114.5	114.4	114.4	114.5	114.5	114.5	114.9	114.6	114.8	114.4	114.7	114.8	114.8
6	Exhaust pressure or vacuum	20.00"	20.00"	10.00"	0.00	20.00"	10.00"	0.00	5.00#	10.00#	15.00#	20.00"	10.00"	0.00	5.00#
7	Abs. exhaust pressure - #/sq.in.	4.53	4.52	9.51	14.37	4.70	9.59	14.49	19.48	24.47	29.46	4.59	9.75	14.65	19.65
8	Calorimeter temperature -deg.F.	259.6	274.1	270.1	264.4	264.6	276.1	275.7	275.1	274.1	268.9	259.1	272.1	274.1	273
9	Quality of steam	.983	.989	.987	.983	.985	.990	.990	.989	.989	.987	.980	.989	.989	.989
10	Room temperature -deg.F.	67	66	59	58	73	70.5	70	68.5	69.5	70	73	70	69	67
11	Rev. per min.	102.1	103	102.5	103.1	104.5	105	104.5	104.1	103.9	103.5	106.3	105.3	104.8	104.4
12	Net weight on brake scales -lb.	292	242	242	242	194	194	194	194	194	194	144	144	144	144
13	Brake horse power	29.81	24.93	24.80	24.95	20.27	20.37	20.28	20.20	20.15	20.09	15.30	15.16	15.10	15.03
14	Mean effective pressure -H.E.	76.48	56.60	58.03	57.20	46.65	45.80	46.00	45.80	45.20	45.80	34.41	34.42	32.96	33.17
15	Mean effective pressure -C.E.	64.40	60.35	57.95	58.55	49.25	49.20	48.00	47.40	47.60	46.80	37.16	36.87	36.46	35.86
16	Indicated horse power -H.E.	17.84	13.33	13.59	13.49	11.15	11.00	10.99	10.90	10.74	10.84	8.37	8.28	7.89	7.92
17	Indicated horse power -C.E.	14.20	13.42	12.83	13.04	11.12	11.16	10.83	10.66	10.69	10.46	8.54	8.38	8.25	8.08
18	Indicated horse power - Total	32.04	26.75	26.42	26.53	22.27	22.16	21.82	21.56	21.43	21.30	16.91	16.66	16.14	16.00
19	Condensate per hr. -lb.	839	692.5	737	781	583	614.5	649	683	730.5	776	481	496	517.5	551.5
20	Condensate per i.h.p. hr. -lb.	26.18	25.90	27.88	29.44	26.19	27.73	29.74	31.69	34.09	36.44	28.44	29.76	32.06	34.47
21	Condensate per b.h.p. hr. -lb	28.15	27.77	29.71	31.31	28.75	30.18	32.00	33.81	36.27	38.65	31.45	32.71	34.26	36.70
22	Dry steam per i.h.p. hr. -lb.	25.73	25.61	27.52	28.94	25.80	27.47	29.44	31.34	33.72	35.97	27.87	29.43	31.71	34.09
23	Dry steam per b.h.p. hr. -lb	27.67	27.46	29.32	30.78	28.32	29.88	31.68	33.44	35.87	38.15	30.82	32.35	33.89	36.30
24	Heat content of steam (i_1) -B.t.u.	1173	1179	1177	1174	1175	1180	1180	1179	1179	1177	1172	1178	1178.5	1178
25	Same after adiab. exp. to p_2 (i_2)-B.t.u.	955.3	960	1001.5	1024	960	1004	1030	1047.5	1064	1075	956	1002.5	1028	1047
26	$i_1 - i_2$ -B.t.u.	217.7	219	175.5	150	215	176	150	131.5	115	102	216	175.5	150.5	131
27	Sensible heat at exh. press. (i_2') -B.t.u.	126.0	125.9	158.7	178.9	127.5	159.2	179.3	194.7	207.2	217.7	126.5	160	179.8	195.2
28	$i_1 - i_2'$ -B.t.u.	1047	1053	1018	995	1048	1021	1001	984	972	959	1045.5	1018	999	983
29	Mechanical efficiency -%	93.1	93.2	93.9	94.1	91.1	92.0	92.9	93.7	94.0	94.3	90.6	91.0	93.6	93.9
30	Thermal efficiency -%	9.29	9.34	8.97	8.69	9.28	8.98	8.55	8.17	7.69	7.28	8.56	8.40	7.95	7.52
31	Potential efficiency -%	44.7	44.9	52.0	57.7	45.2	52.1	57.1	61.1	65.0	68.5	41.4	48.7	52.7	56.4
32	Ratio of expansion.	3.23	4.41	3.88	3.34	5.94	5.16	4.51	3.88	3.38	3.00	8.95	7.72	6.44	5.51

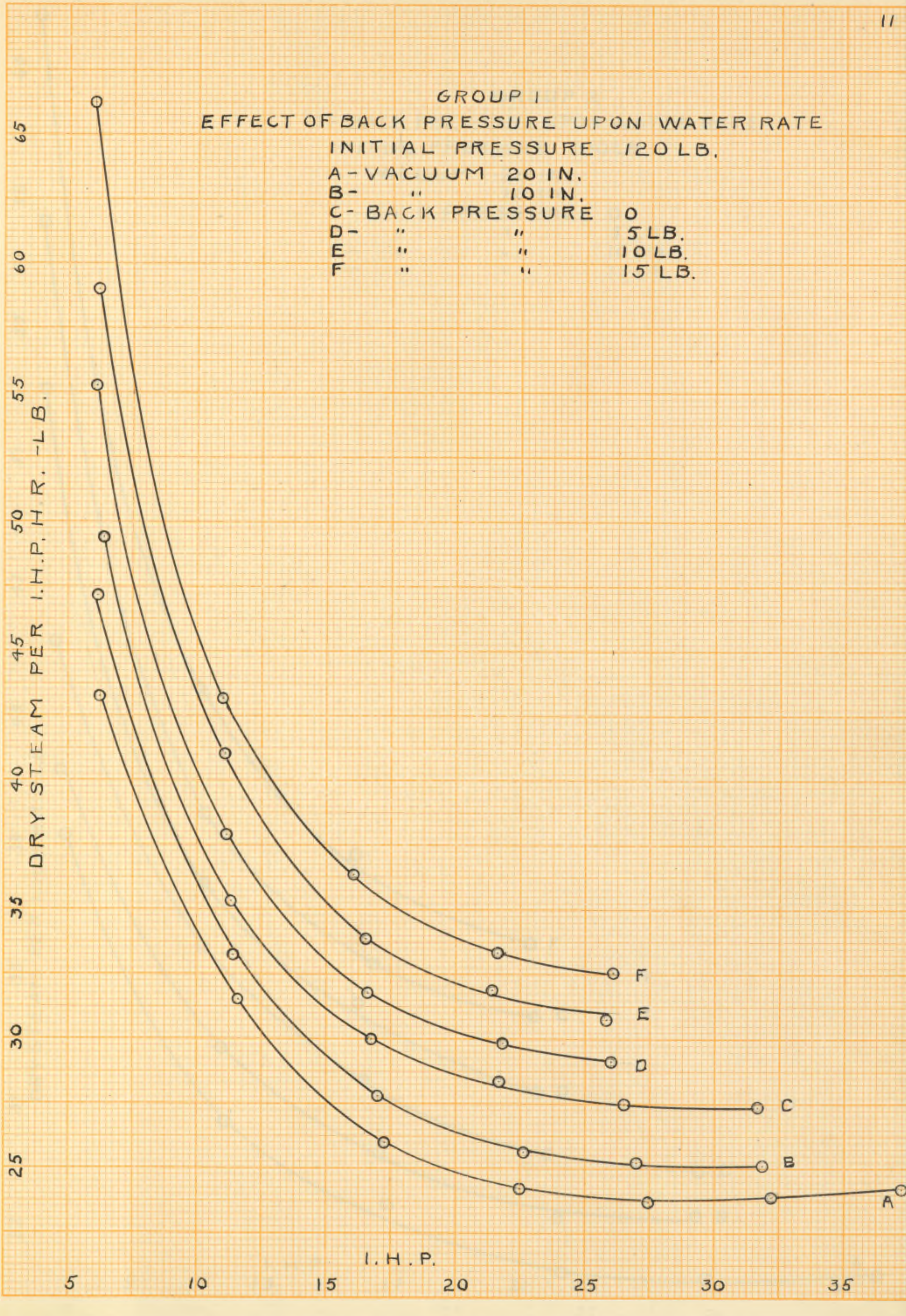
No.	Name of Item.	Trial Number 94	43	55	56	57	58	59	60	78	77	76	75	74	73
1	Duration of trial -hr.	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Barometer -In. of Hg.	29.16	29.72	29.62	29.62	29.60	29.38	29.35	29.32	29.26	29.26	29.26	29.27	29.26	29.11
3	Atmospheric pressure -#/sq.in.	14.31	14.59	14.54	14.54	14.53	14.42	14.41	14.39	14.36	14.36	14.36	14.37	14.36	14.29
4	Steam pressure -#/sq.in.	100.0	100.1	100.0	100.0	100.0	100.3	100.3	100.1	100.0	100.0	100.0	99.9	100.0	100.0
5	Abs. steam pressure -#sq.in.	114.3	114.7	114.5	114.5	114.5	114.7	114.7	114.5	114.4	114.4	114.4	114.5	114.4	114.3
6	Exhaust pressure or vacuum	10.00#	15.00#	20.00"	10.00"	0.00	5.00#	10.00#	15.00#	20.00"	10.00"	0.00	5.00#	10.00#	15.00#
7	Abs. exhaust pressure - #/sq.in.	24.31	29.59	4.72	9.63	14.53	19.42	24.41	29.39	4.54	9.45	14.36	19.37	24.36	29.29
8	Calorimeter temperature -deg.F.	259.3	273	270.3	269.1	269.3	266.9	267.6	268.9	264.9	265.4	265.9	265.6	264.2	265.4
9	Quality of steam	.983	.989	.987	.987	.987	.986	.986	.987	.985	.985	.985	.985	.984	.985
10	Room temperature -deg.F.	70	69	70	65	73	63.5	65	74	60	69	68	65	66	69
11	Rev. per min.	104.7	103.3	107.7	106.9	106.5	105.8	105.1	104.3	109.7	109.4	108.3	107.3	106.6	105.9
12	Net weight on brake scales -lb.	144	144	95	95	95	95	95	95	47	47	47	47	47	47
13	Brake horse power	15.08	14.87	10.23	10.15	10.12	10.05	9.99	9.91	5.15	5.14	5.09	5.04	5.01	4.98
14	Mean effective pressure -H.E.	34.42	33.17	23.63	23.84	21.35	22.60	23.02	22.60	13.89	13.48	12.86	12.23	11.82	12.23
15	Mean effective pressure -C.E.	36.46	36.26	26.13	25.73	26.13	25.12	25.12	25.12	14.59	14.50	14.59	14.39	14.50	13.78
16	Indicated horse power -H.E.	8.24	7.83	5.82	5.82	5.19	5.47	5.53	5.39	3.48	3.37	3.18	3.00	2.88	2.96
17	Indicated horse power -C.E.	8.26	8.10	6.08	5.94	6.00	5.75	5.71	5.66	3.46	3.43	3.42	3.33	3.34	3.15
18	Indicated horse power - Total	16.50	15.93	11.90	11.76	11.19	11.22	11.24	11.05	6.94	6.80	6.60	6.33	6.22	6.11
19	Condensate per hr. -lb.	593	623	367	390	406.5	430	455	491	277.5	285	303.5	341	368.5	401.5
20	Condensate per i.h.p. hr. -lb.	35.93	39.11	30.85	33.16	36.33	38.33	40.53	44.43	39.97	41.90	45.97	53.88	59.25	65.70
21	Condensate per b.h.p. hr. -lb	39.40	41.90	35.89	38.43	40.17	42.80	45.96	49.55	53.90	55.50	59.60	67.70	73.15	80.65
22	Dry steam per i.h.p. hr. -lb.	35.32	38.68	30.45	32.73	35.86	37.79	39.96	43.85	39.37	41.27	45.28	53.07	58.30	64.71
23	Dry steam per b.h.p. hr. -lb	38.73	41.44	35.42	37.93	39.65	42.20	45.32	48.91	53.09	54.67	58.71	66.62	71.98	79.44
24	Heat content of steam (i_1) -B.t.u.	1173	1178.5	1177	1177	1177	1176	1176	1177	1175	1175.5	1175.5	1175.5	1174.5	1175
25	Same after adiab. exp. to p_2 (i_2)-B.t.u.	1059	1075.5	961	1001	1027	1045.5	1061	1075	957	1000	1025.5	1045	1060	1073
26	$i_1 - i_2$ -B.t.u.	114	103	216	176	150	130.5	115	102	218	175.5	150	130.5	114.5	102
27	Sensible heat at exh. press. (i_2') -B.t.u.	206.8	218	127.7	159.4	179.4	194.6	207	217.5	126.1	158.5	178.8	194.4	206.9	217.4
28	$i_1 - i_2'$ -B.t.u.	966	960	1049	1018	998	981	969	960	1049	1017	997	981	968	958
29	Mechanical efficiency -%	91.4	93.5	86.0	86.3	90.5	89.6	88.9	89.6	74.2	75.6	77.1	79.6	80.8	81.5
30	Thermal efficiency -%	7.34	6.78	7.52	7.54	7.02	6.77	6.48	5.95	6.07	5.97	6.56	4.82	4.44	4.05
31	Potential efficiency -%	43.7	63.2	36.5	43.6	46.7	50.9	54.6	55.2	29.2	34.6	36.9	36.2	37.5	38.0
32	Ratio of expansion.	4.60	4.15	14.59	11.70	9.61	7.82	6.71	5.50	29.36	19.89	15.97	11.92	9.78	8.15

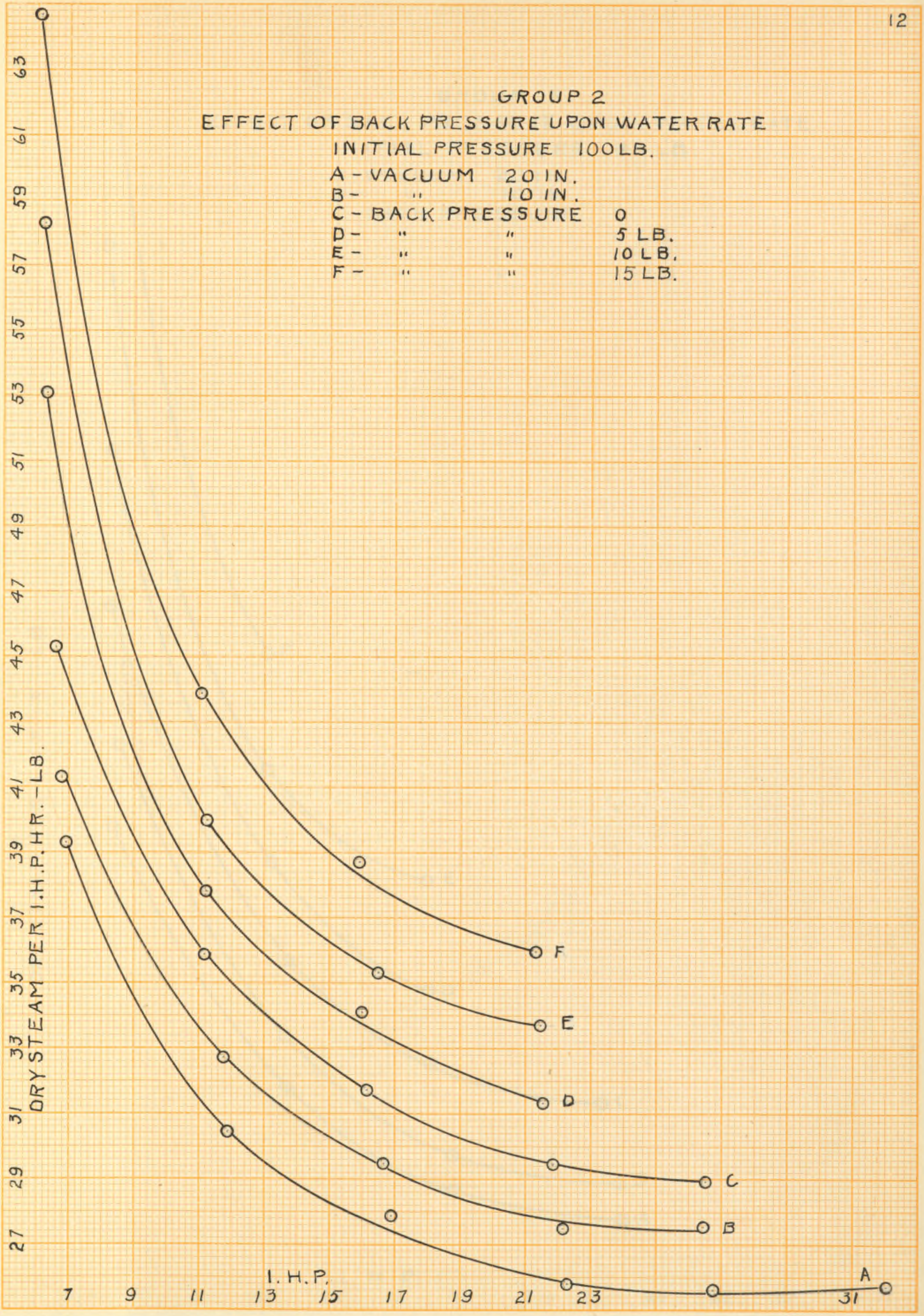
The Effect of Initial and Back Pressures upon the Water Rate of a Simple Steam Engine.

Results of Tests, Table No. 3 - Initial Pressure - 80 lb.

H. F. Godeke

No.	Name of Item.	Trial Number																				
		102	103	25	24	36	97	98	99	40	66	96	64	63	62	61	79	80	81	82	83	84
1	Duration of trial - hr.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Barometer - in. of Hg	29.35	29.35	29.28	29.25	29.75	29.33	29.30	29.30	29.73	29.19	29.40	29.16	29.27	29.27	29.29	29.26	29.18	29.10	29.04	29.04	29.38
3	Atmospheric pressure - #/sq.in.	14.41	14.41	14.37	14.36	14.60	14.40	14.38	14.38	14.59	14.33	14.43	14.31	14.37	14.37	14.38	14.36	14.32	14.28	14.26	14.26	14.42
4	Steam pressure - #/sq.in.	80.0	80.0	79.9	80.0	80.6	80.0	80.0	80.0	80.4	80.0	80.0	80.3	80.1	80.0	80.4	80.0	80.0	79.8	80.0	80.0	80.0
5	Abs. steam pressure - #/sq.in.	94.4	94.4	9.43	94.4	95.2	94.4	94.4	94.4	95	94.3	94.4	94.6	94.5	94.4	94.8	94.4	94.3	94.1	94.3	94.3	94.4
6	Exhaust pressure or vacuum	20.00"	20.00"	10.00"	0.00	20.00"	10.00"	0.00	5.00#	10.00#	20.00"	10.00"	0.00	5.00#	10.00#	15.00#	20.00"	10.00"	0.00	5.00#	10.00#	15.00#
7	Abs. exhaust pressure - #/sq.in.	4.59	4.59	9.46	14.36	4.78	9.49	14.38	19.38	24.59	4.51	9.52	14.31	19.37	24.37	29.38	4.54	9.41	14.28	19.26	24.26	29.42
8	Calorimeter temperature - deg.F.	245.8	248.7	261.6	264.7	259.2	255.4	254.9	260.4	266	265.9	262.1	262.2	261.2	261.5	262.1	252.1	253	252	253.6	255.4	262.4
9	Quality of steam	.978	.980	.987	.988	.985	.985	.984	.987	.989	.989	.988	.987	.987	.987	.988	.982	.982	.982	.983	.983	.988
10	Room temperature - deg.F.	73	73.5	56	58	69	67	67	68	66	68	69.5	68	74.5	69	68	64	70	70	69	69.5	64
11	Rev. per min.	102.7	103.5	103.5	102.8	105.2	104.6	103.8	103.3	102.8	106.8	106.7	105.1	104.4	103.8	103.0	109.3	109.0	108.1	107.0	106.1	104.2
12	Net weight on brake scales - lb.	242	194	194	194	144	144	144	144	144	95	95	95	96	96	97	47	47	47	47	47	47
13	Brake horse power	24.85	20.09	20.08	19.95	15.15	15.06	14.95	14.87	14.80	10.15	10.13	9.99	10.01	9.97	9.99	5.14	5.12	5.08	5.03	4.99	4.91
14	Mean effective pressure - H.E.	58.05	46.44	46.60	46.20	34.63	34.83	34.85	34.62	34.00	22.81	23.13	24.26	23.22	23.02	23.42	13.68	12.65	12.44	12.23	11.61	13.27
15	Mean effective pressure - C.E.	58.13	49.00	48.60	47.40	37.27	37.27	34.83	35.04	36.06	26.54	25.93	26.13	25.12	25.12	25.12	13.78	14.50	13.78	14.18	14.59	14.73
16	Indicated horse power - H.E.	13.62	10.99	11.03	10.86	8.33	8.33	8.27	8.18	7.96	5.56	5.64	5.82	5.54	5.46	5.51	3.13	3.15	3.07	2.99	2.82	3.16
17	Indicated horse power - C.E.	12.89	10.96	10.87	10.52	8.47	8.42	7.81	7.82	8.01	6.12	5.98	5.93	5.67	5.64	5.59	3.25	3.41	3.22	3.28	3.34	3.32
18	Indicated horse power - Total	26.51	21.95	21.90	21.38	16.80	16.75	16.08	16.00	15.97	11.68	11.62	11.75	11.21	11.10	11.10	6.38	6.56	6.29	6.27	6.16	6.48
19	Condensate per hour - lb.	762	622	641	678.5	488.5	506	532.5	561.5	616	376	393	424	439	464.5	501	258.5	282.5	298	327.5	361	403.5
20	Condensate per i.h.p. hr. - lb.	28.73	28.34	29.26	31.75	29.08	30.21	33.08	35.20	38.56	32.20	33.81	36.10	39.17	41.85	45.64	40.52	43.07	47.37	52.23	58.60	62.28
21	Condensate per b.h.p. hr. - lb.	30.67	30.97	31.94	34.00	32.24	33.60	35.62	37.76	41.61	37.06	38.80	42.45	43.85	46.58	50.15	50.40	55.65	58.70	65.10	72.40	82.15
22	Dry steam per i.h.p. hr. - lb.	28.10	27.77	28.88	31.37	28.64	29.76	32.55	34.74	38.14	31.85	33.40	35.63	38.66	41.31	45.09	39.79	42.30	46.56	51.34	57.60	61.53
23	Dry steam per b.h.p. hr. - lb.	30.00	30.35	31.52	33.59	31.61	33.10	35.05	34.25	41.15	36.65	32.93	41.90	43.28	45.98	49.55	49.49	54.65	57.64	64.00	71.17	81.16
24	Heat content of steam (i_1) - B.t.u.	1166	1167	1173	1175	1172	1171.5	1171	1173	1175.5	1175.5	1174	1174	1173.5	1173.5	1174	1169	1169.5	1169	1170	1170.5	1174
25	Same after adiab. exp. to p_2 (i_2) - B.t.u.	963.5	964.5	1010.5	1038	970	1008.5	1035	1056	1075.5	968.5	1011.5	1038	1057	1073	1086	965	1007	1032	1054.5	1070	1086
26	$i_1 - i_2$ - B.t.u.	202.5	202.5	162.5	137	202	163	136	117	100	207	162.5	136	116.5	100.5	88	204	162.5	137	115.5	100.5	88
27	Sensible heat at exh. press. (i'_2) - B.t.u.	126.5	126.5	158.5	178.5	128.2	158.7	178.9	194.4	207.5	125.8	158.8	178.6	194.4	206.9	217.5	126.1	158.8	178.5	194.1	206.7	217.6
28	$i_1 - i'_2$ - B.t.u.	1039.5	1040.5	1015	996	1044	1013	992	979	968	1050	1015	995	979	967	957	1043	1011	991	976	964	956
29	Mechanical efficiency - %	93.7	91.5	91.7	93.4	90.2	89.9	93.0	92.9	92.7	86.9	87.2	85.0	89.3	88.8	90.0	80.6	78.0	80.8	80.2	81.0	75.8
30	Thermal efficiency - %	8.53	8.63	8.57	8.05	8.40	8.32	7.76	7.39	7.14	7.53	7.42	7.09	6.64	6.29	5.83	6.02	5.85	5.42	4.99	4.51	4.28
31	Potential efficiency - %	43.8	44.3	53.5	58.5	43.4	51.7	56.6	61.8	69.2	38.2	46.3	51.8	55.80	60.6	63.4	30.8	36.4	39.2	42.2	43.2	46.5
32	Ratio of expansion	3.1	4.48	3.68	3.18	6.88	5.46	4.61	3.86	3.32	11.17	8.91	7.10	5.77	4.72	3.95	21.12	16.53	12.04	9.31	7.30	5.75


GROUP I
EFFECT OF BACK PRESSURE UPON WATER RATE
INITIAL PRESSURE 120 LB.
A - VACUUM 20 IN.
B - " 10 IN.
C - BACK PRESSURE 0
D - " " 5 LB.
E " " 10 LB.
F " " 15 LB.
DRY STEAM PER I.H.P. HR. - LB.
65
60
55
50
45
40
35
30
25
I.H.P.
5
10
15
20
25
30
35
A
B
C
D
E
F


GROUP 2
EFFECT OF BACK PRESSURE UPON WATER RATE
INITIAL PRESSURE 100 LB.
A - VACUUM 20 IN.
B - " 10 IN.
C - BACK PRESSURE 0
D - " " 5 LB.
E - " " 10 LB.
F - " " 15 LB.
DRY STEAM PER I.H.P. HR. - LB.
I. H. P.
A
B
C
D
E
F
7
9
11
13
15
17
19
21
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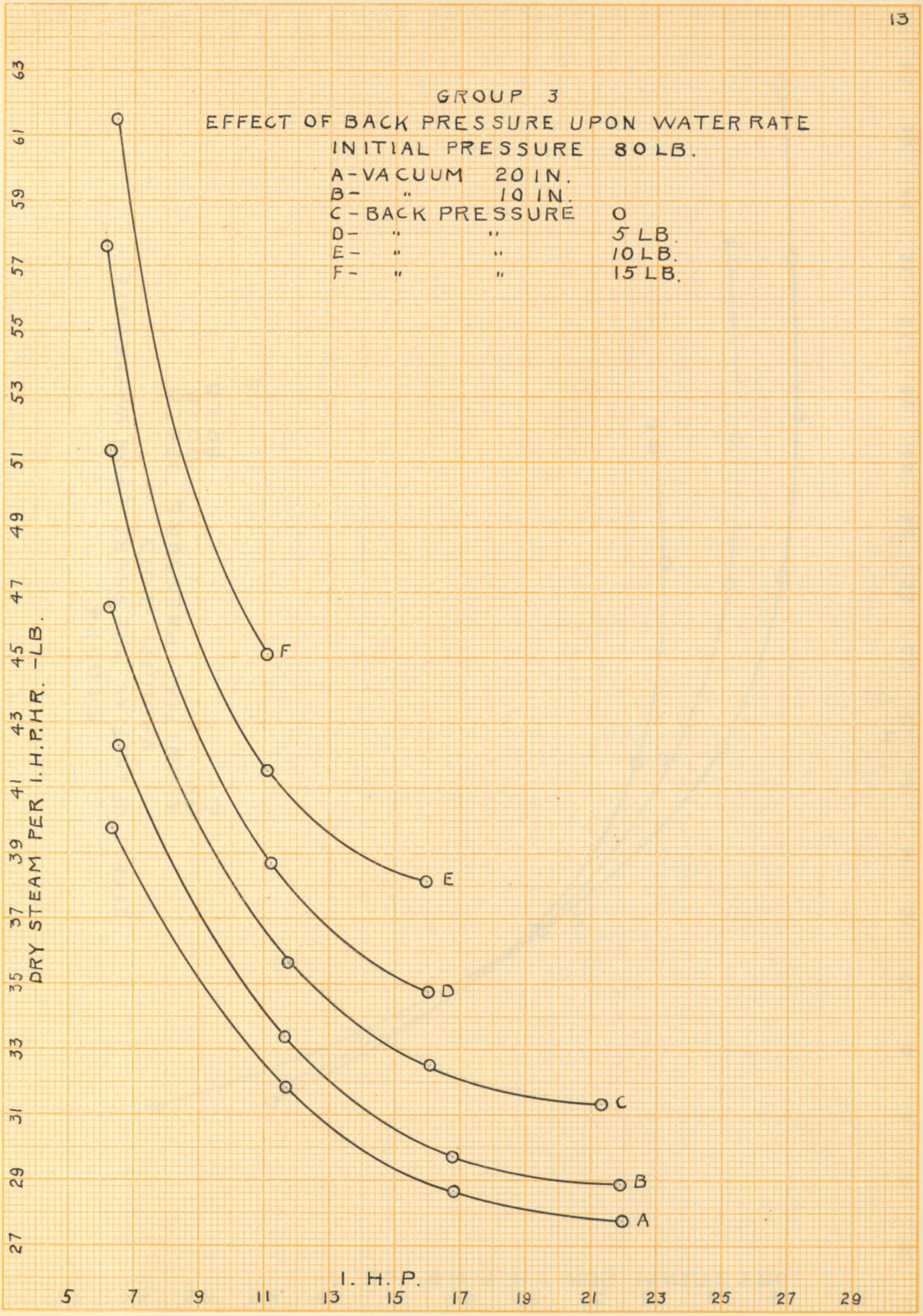
GROUP 3
EFFECT OF BACK PRESSURE UPON WATER RATE
INITIAL PRESSURE 80 LB.
A-VACUUM 20 IN.
B- " 10 IN.
C-BACK PRESSURE 0
D- " " 5 LB.
E- " " 10 LB.
F- " " 15 LB.
DRY STEAM PER I.H.P.HR. -LB.
I. H. P.
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29
31
33
35
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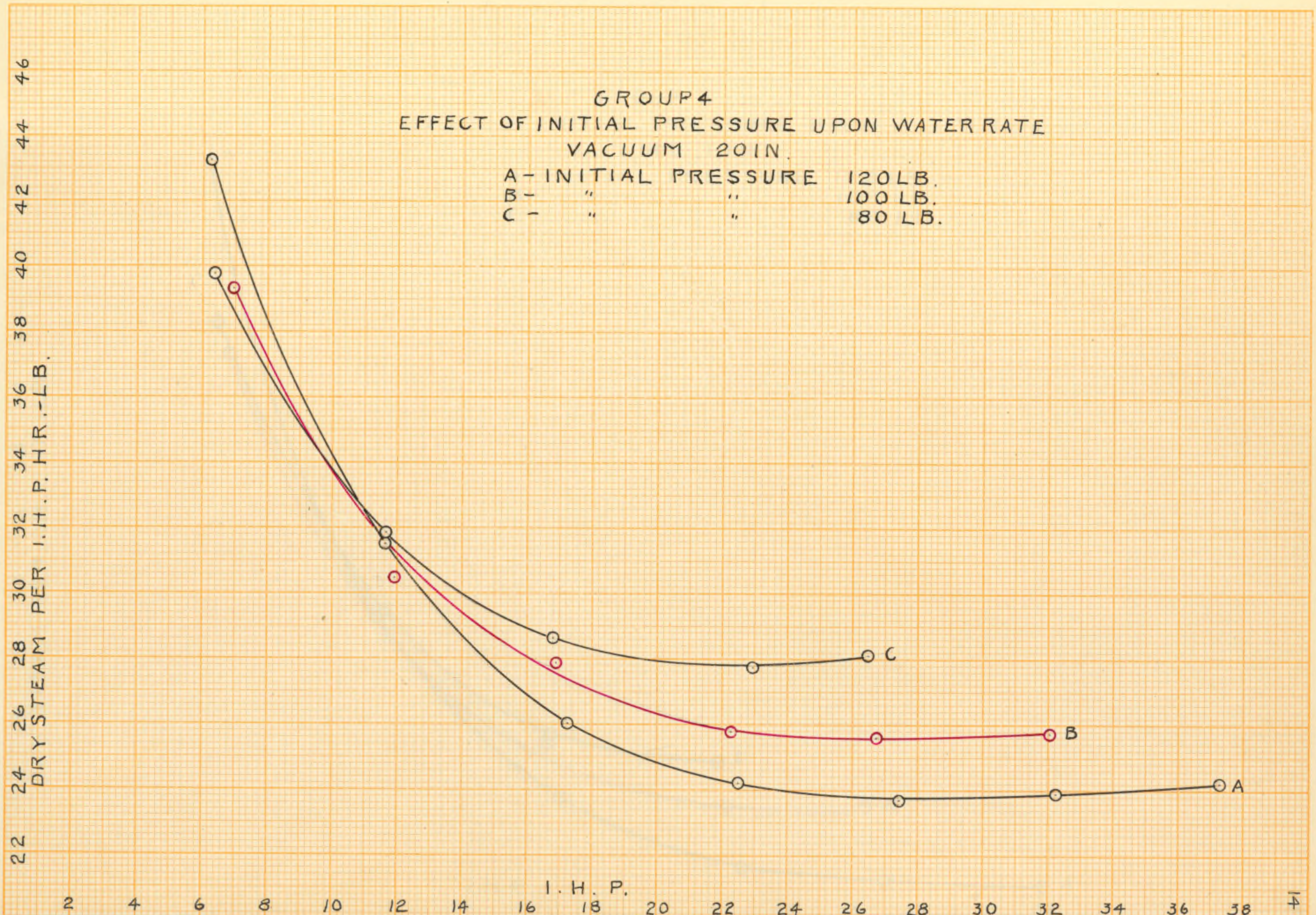
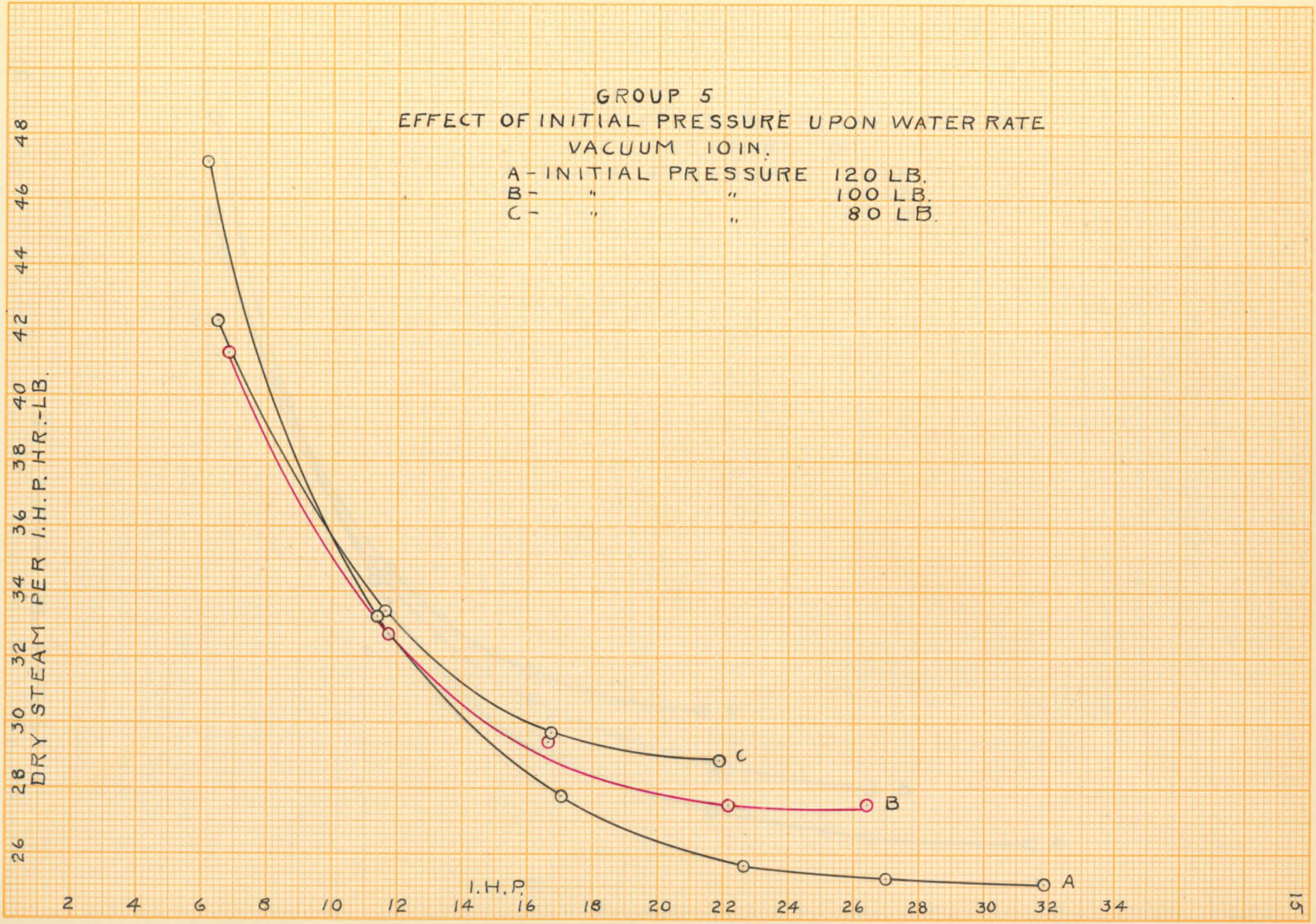
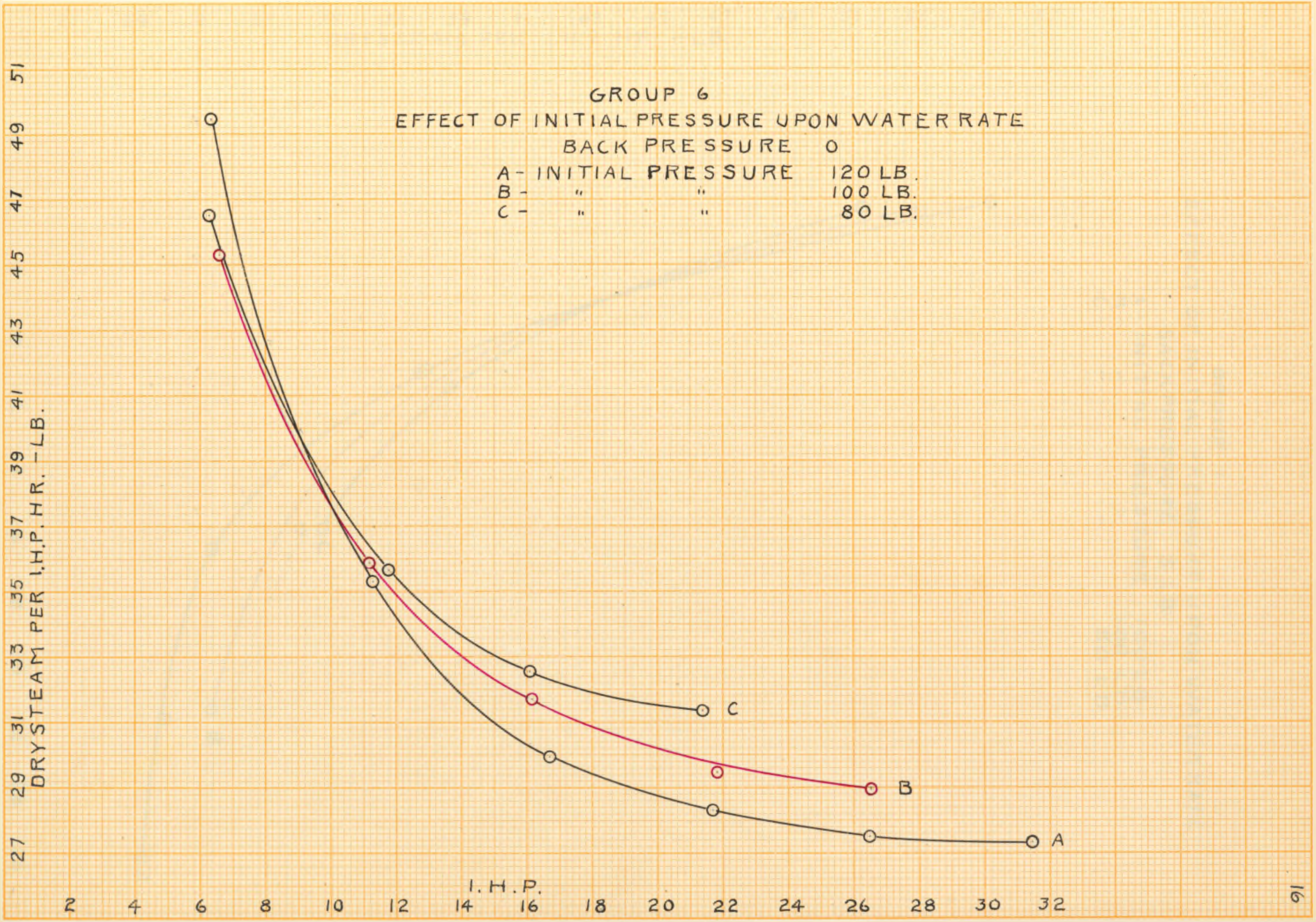
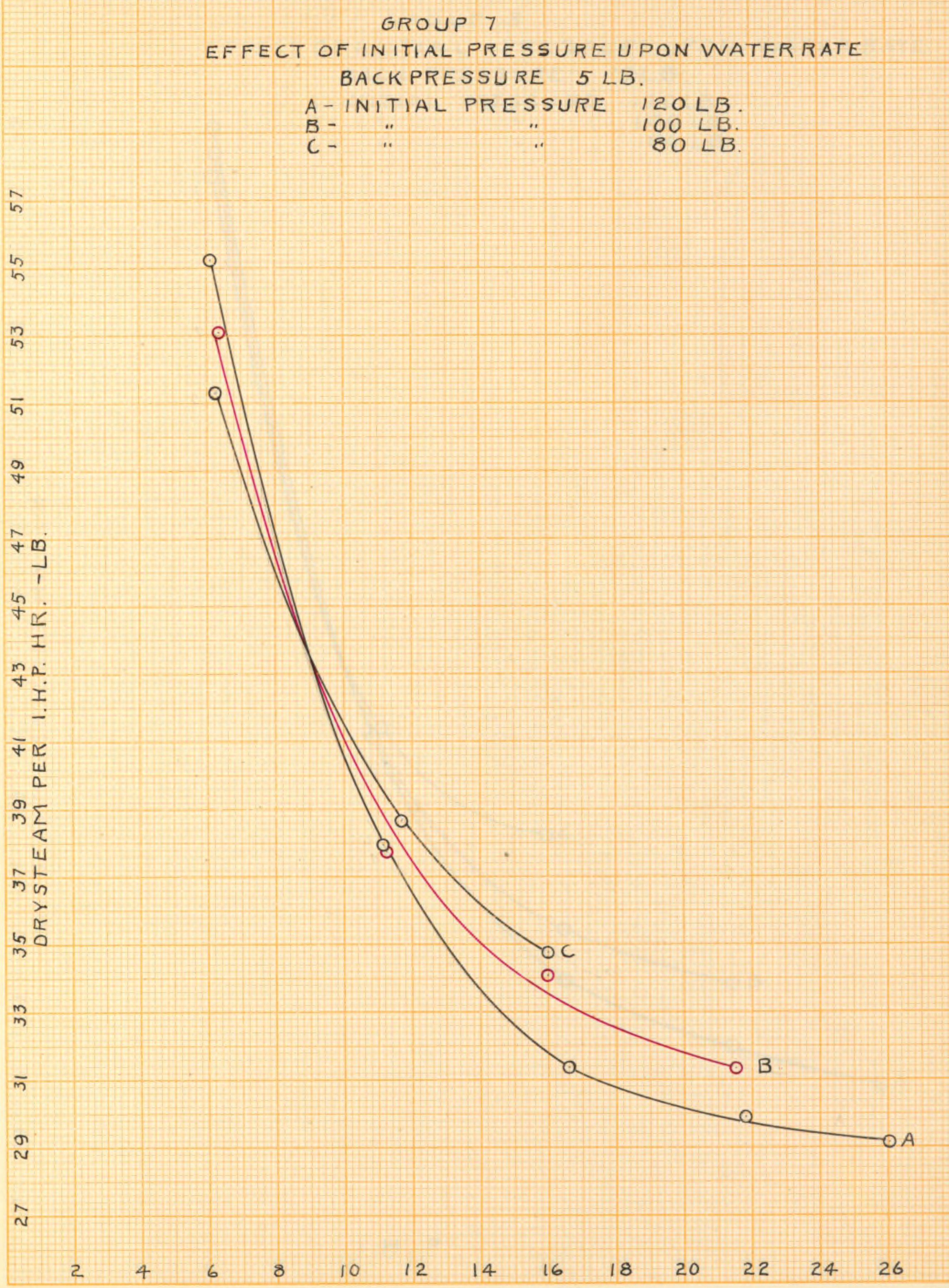
21
23
25
27
29
A
B
C
D
E
F

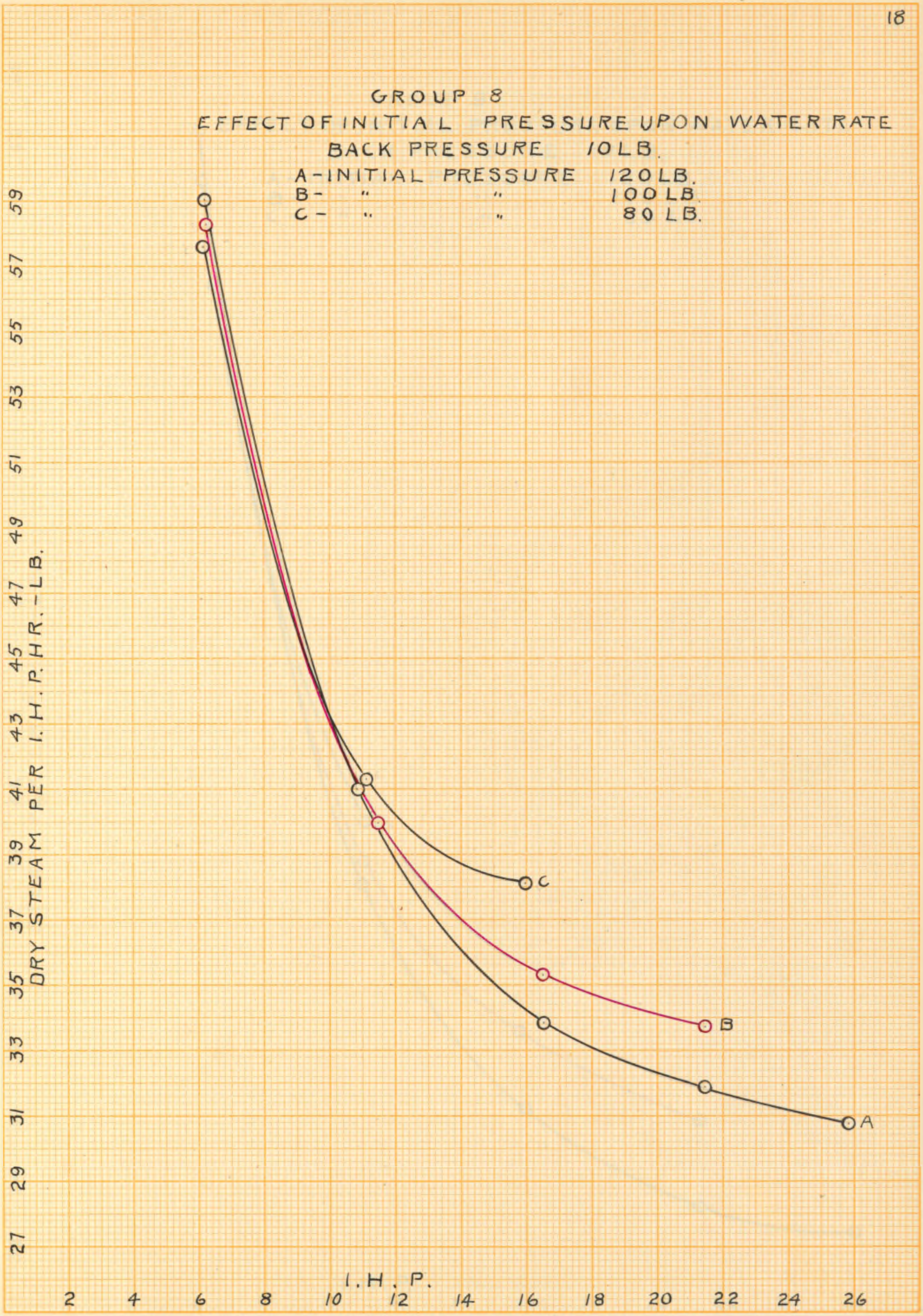


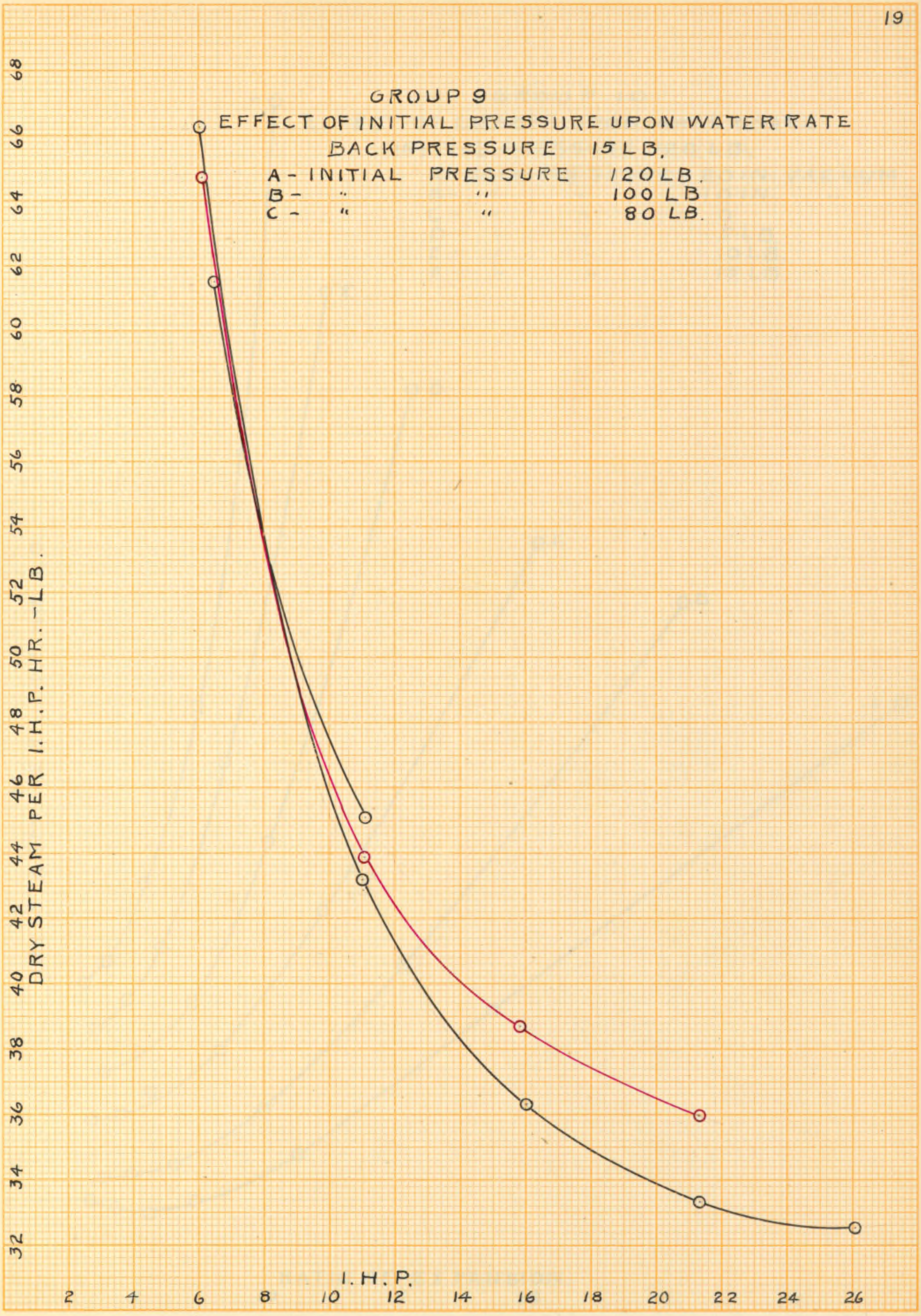
GROUP 4
EFFECT OF INITIAL PRESSURE UPON WATER RATE
VACUUM 20 IN.
A - INITIAL PRESSURE 120 LB.
B - " " 100 LB.
C - " " 80 LB.
DRY STEAM PER I.H.P. HR. - LB.
22
24
26
28
30
32
34
36
38
40
42
44
46
I. H. P.
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
A
B
C

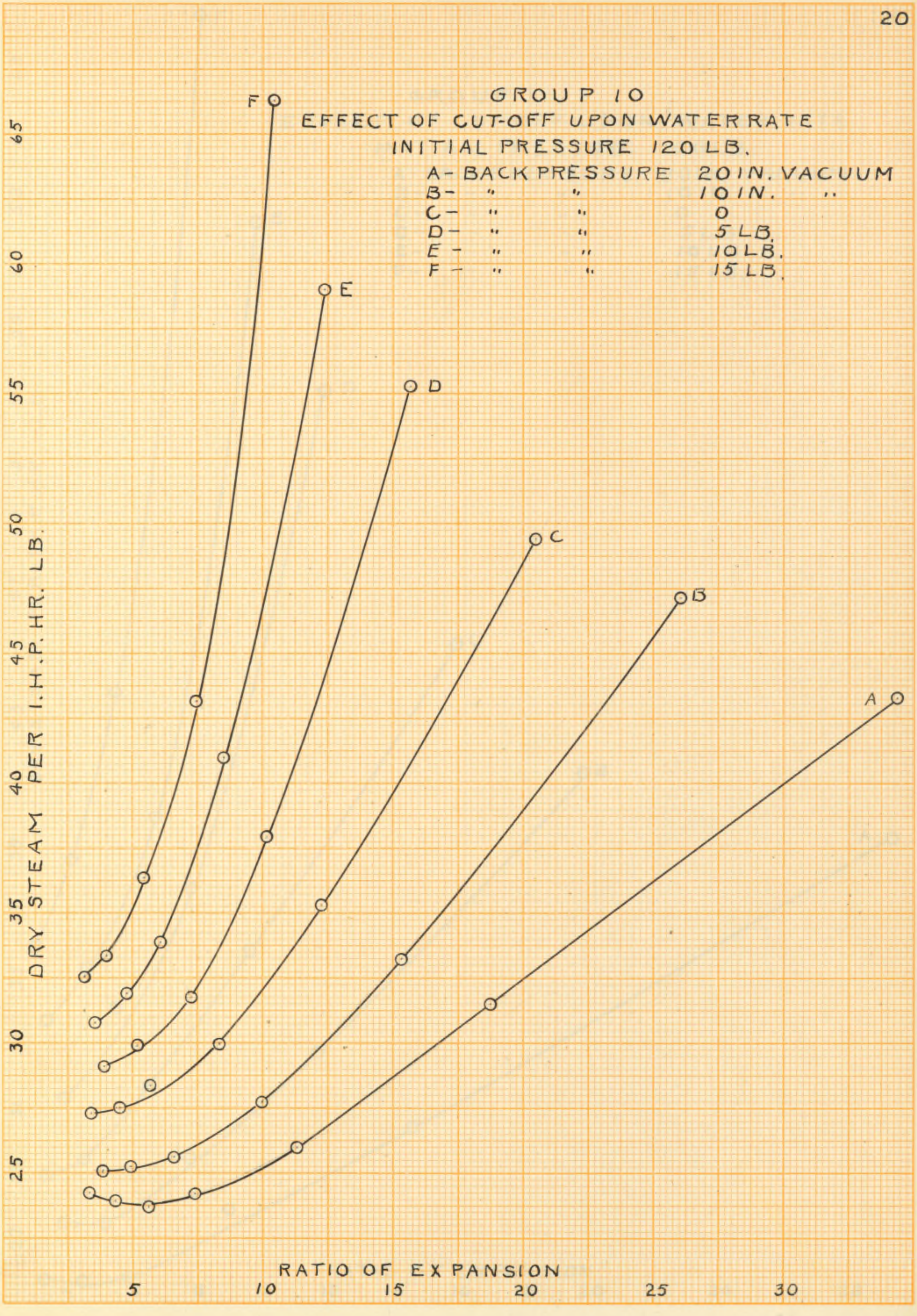

GROUP 5
EFFECT OF INITIAL PRESSURE UPON WATER RATE
VACUUM 10 IN.
A - INITIAL PRESSURE 120 LB.
B - " " 100 LB.
C - " " 80 LB.
DRY STEAM PER I.H.P. HR.-LB.
26
28
30
32
34
36
38
40
42
44
46
48
I.H.P.
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
A
B
C
15

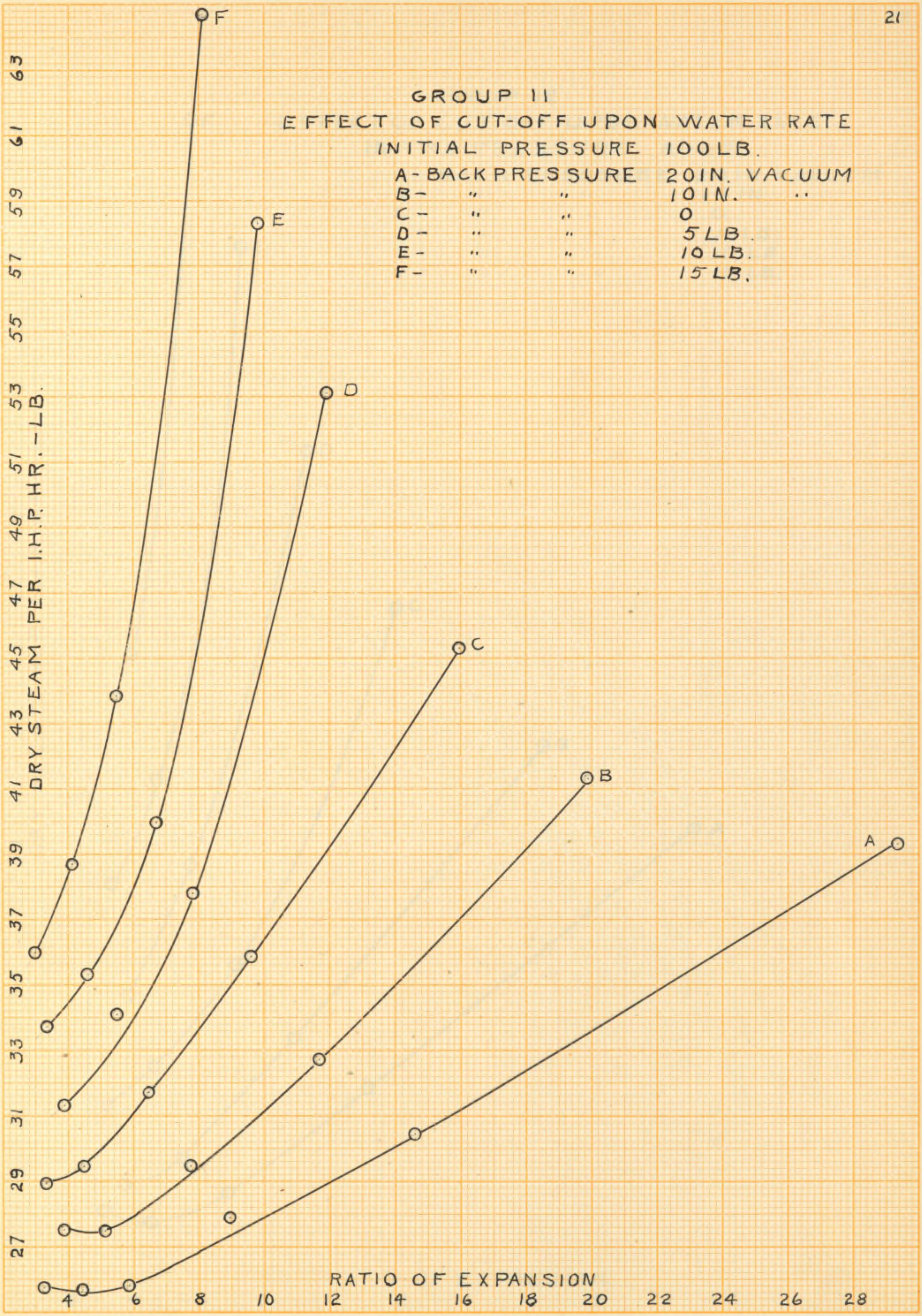

GROUP 6
EFFECT OF INITIAL PRESSURE UPON WATER RATE
BACK PRESSURE 0
A - INITIAL PRESSURE 120 LB.
B - " " 100 LB.
C - " " 80 LB.
DRY STEAM PER I.H.P. HR. - LB.
27
29
31
33
35
37
39
41
43
45
47
49
51
I. H. P.
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
A
B
C

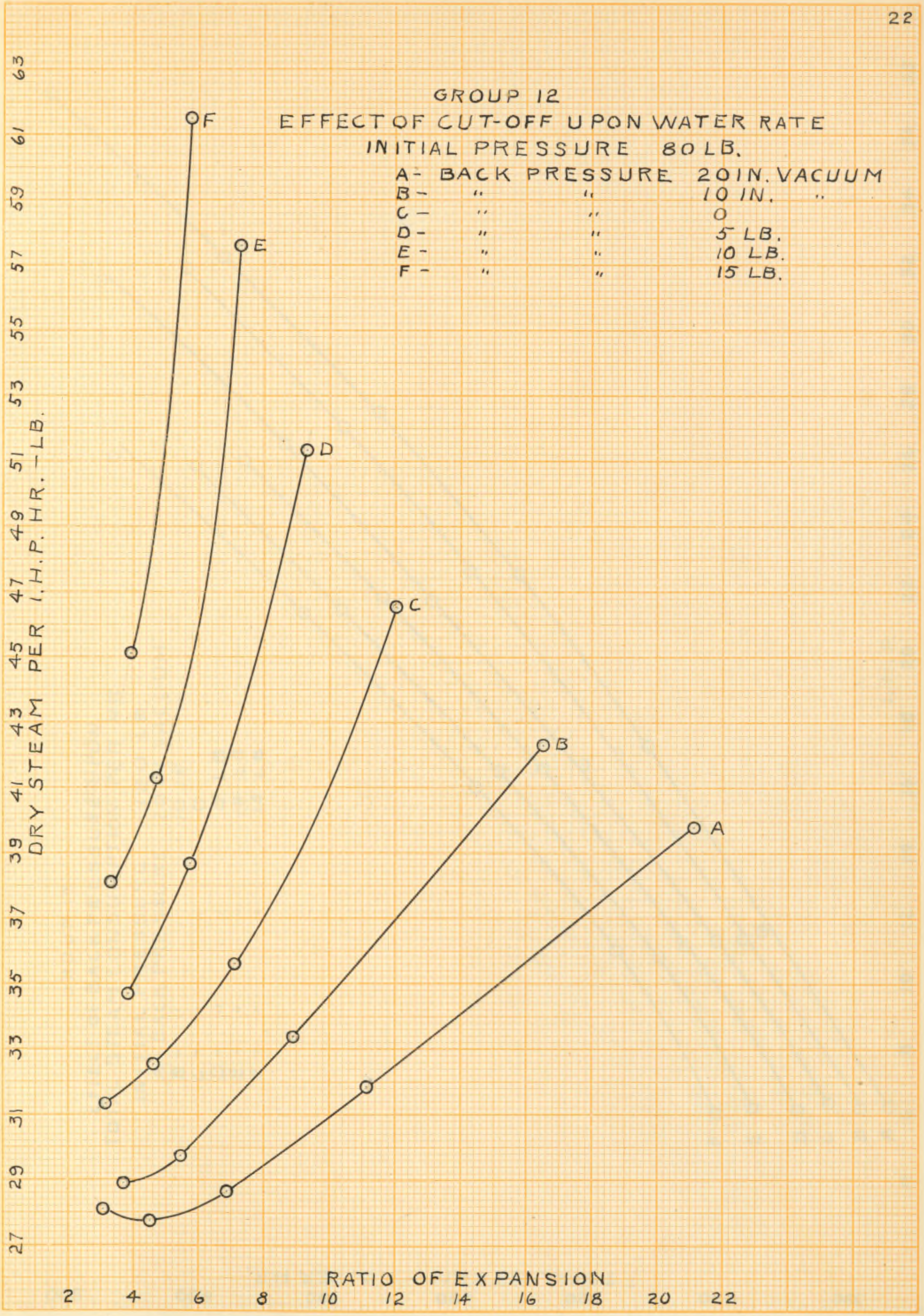

GROUP 7
EFFECT OF INITIAL PRESSURE UPON WATER RATE
BACK PRESSURE 5 LB.
A - INITIAL PRESSURE 120 LB.
B - " " 100 LB.
C - " " 80 LB.
DRY STEAM PER I.H.P. HR. - LB.
57
55
53
51
49
47
45
43
41
39
37
35
33
31
29
27
2
4
6
8
10
12
14
16
18
20
22
24
26
A
B
C

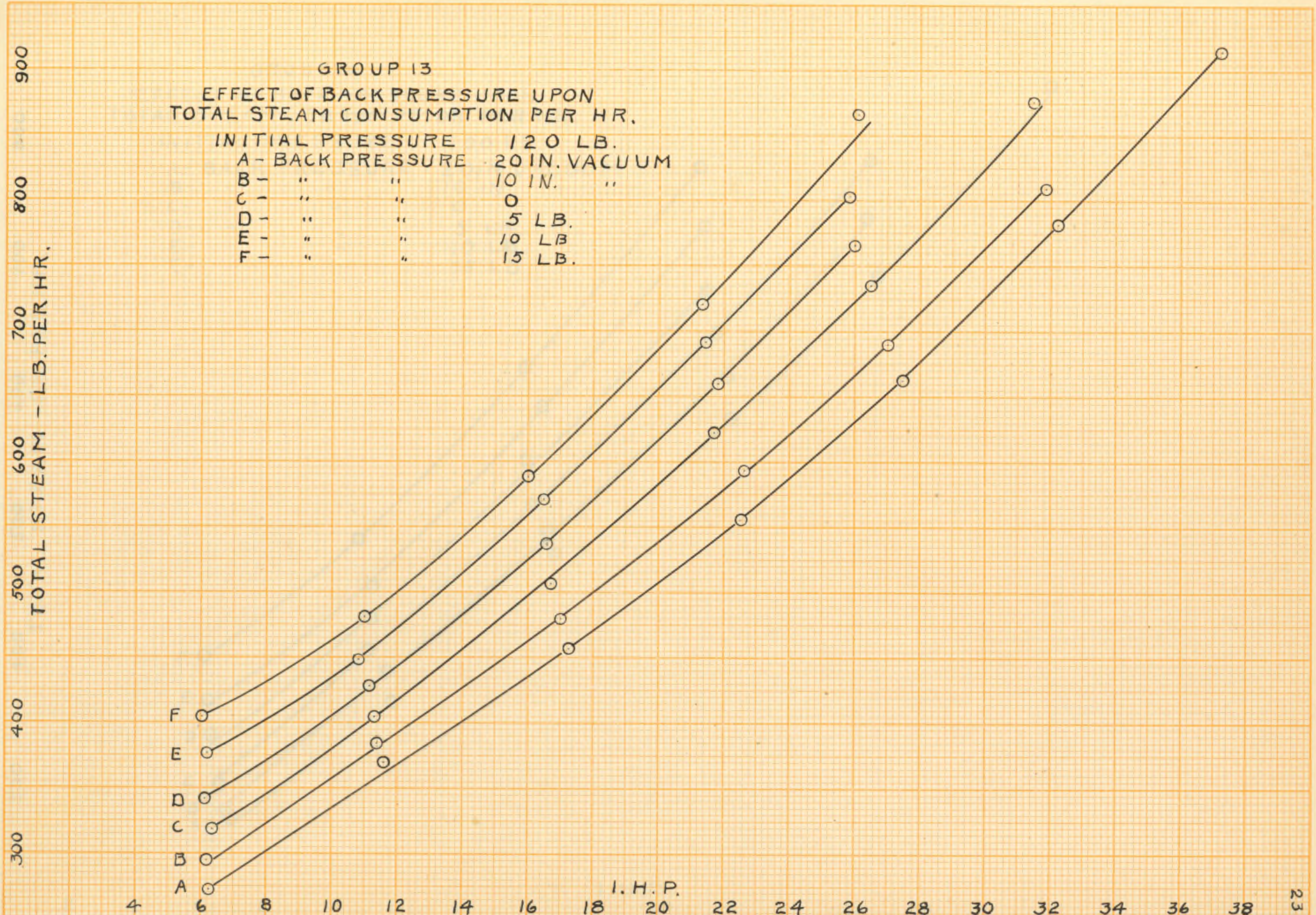

GROUP 8
EFFECT OF INITIAL PRESSURE UPON WATER RATE
BACK PRESSURE 10 LB.
A-INITIAL PRESSURE 120 LB.
B- " " 100 LB.
C- " " 80 LB.
DRY STEAM PER I.H.P. HR. - LB.
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59
I.H.P.
2
4
6
8
10
12
14
16
18
20
22
24
26
A
B
C

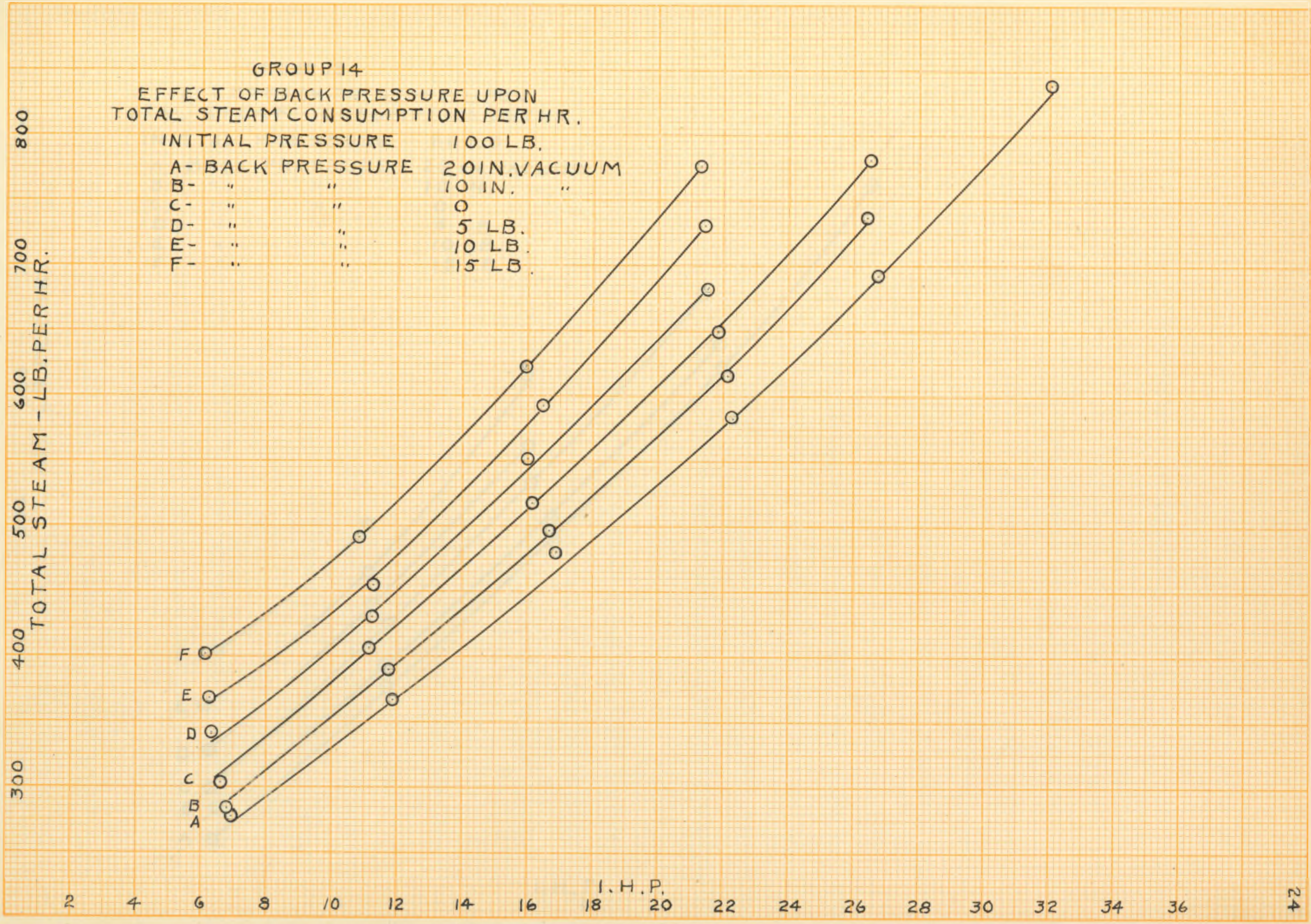

GROUP 9
EFFECT OF INITIAL PRESSURE UPON WATER RATE
BACK PRESSURE 15 LB.
A - INITIAL PRESSURE 120 LB.
B - " " 100 LB
C - " " 80 LB.
DRY STEAM PER I.H.P. HR. - LB.
I.H.P.
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
2
4
6
8
10
12
14
16
18
20
22
24
26


GROUP 10
EFFECT OF CUT-OFF UPON WATER RATE
INITIAL PRESSURE 120 LB.
A- BACK PRESSURE 20 IN. VACUUM
B- " " 10 IN. "
C- " " 0
D- " " 5 LB.
E- " " 10 LB.
F- " " 15 LB.
F
E
D
C
B
A
DRY STEAM PER I.H.P. HR. LB.
25
30
35
40
45
50
55
60
65
RATIO OF EXPANSION
5
10
15
20
25
30

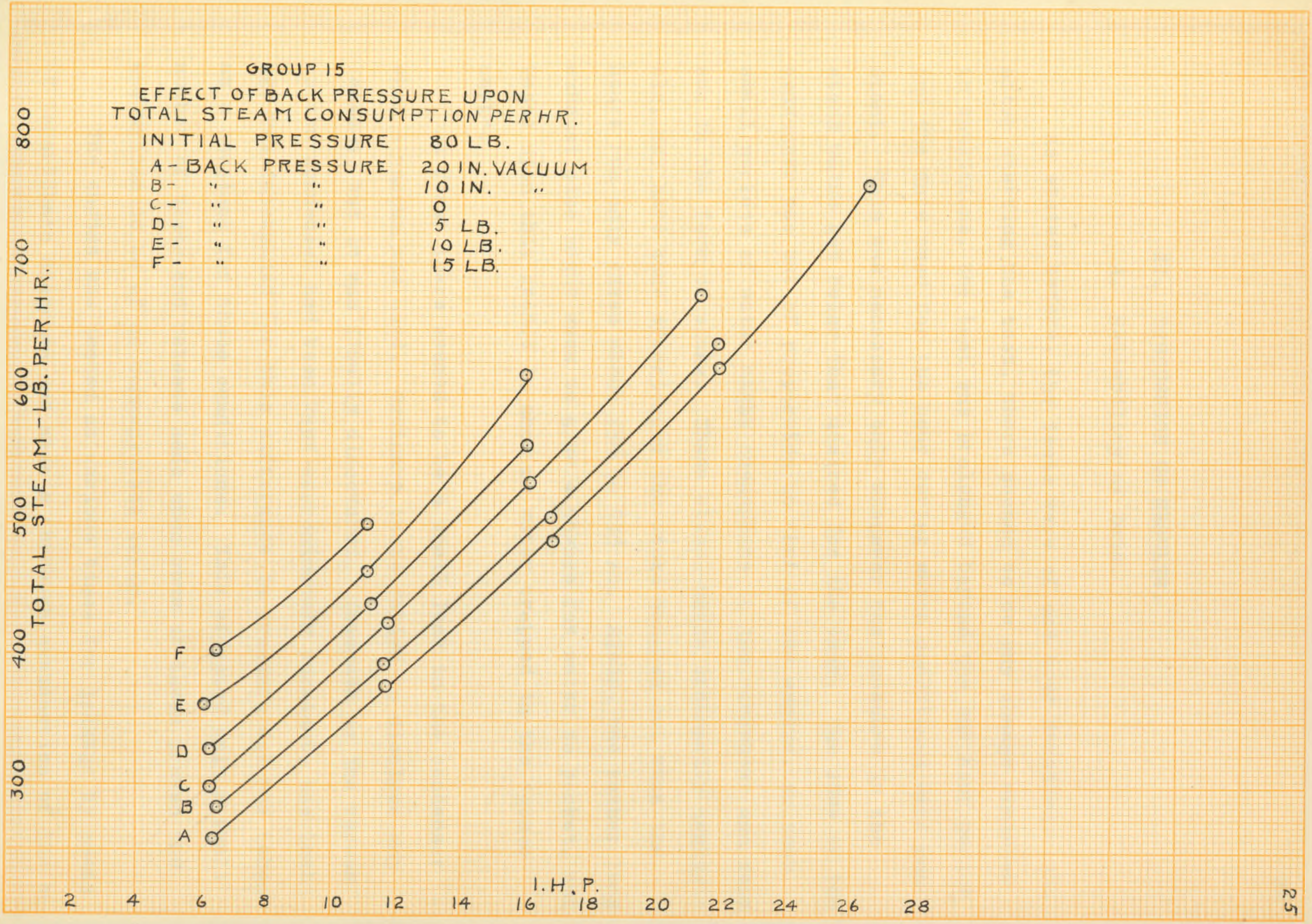

GROUP II
EFFECT OF CUT-OFF UPON WATER RATE
INITIAL PRESSURE 100 LB.
A - BACK PRESSURE 20 IN. VACUUM
B - " " 10 IN. "
C - " " 0
D - " " 5 LB.
E - " " 10 LB.
F - " " 15 LB.
DRY STEAM PER I.H.P. HR. - LB.
RATIO OF EXPANSION
A
B
C
D
E
F
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59
61
63
4
6
8
10
12
14
16
18
20
22
24
26
28


GROUP 12
EFFECT OF CUT-OFF UPON WATER RATE
INITIAL PRESSURE 80 LB.
A - BACK PRESSURE 20 IN. VACUUM
B - " " 10 IN. "
C - " " 0
D - " " 5 LB.
E - " " 10 LB.
F - " " 15 LB.
DRY STEAM PER I.H.P. HR. - LB.
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59
61
63
RATIO OF EXPANSION
2
4
6
8
10
12
14
16
18
20
22
A
B
C
D
E
F


GROUP 13
EFFECT OF BACK PRESSURE UPON
TOTAL STEAM CONSUMPTION PER HR.
INITIAL PRESSURE 120 LB.
A - BACK PRESSURE 20 IN. VACUUM
B - " " 10 IN. "
C - " " 0
D - " " 5 LB.
E - " " 10 LB
F - " " 15 LB.
TOTAL STEAM - LB. PER HR.
900
800
700
600
500
400
300
F
E
D
C
B
A
I. H. P.
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38



GROUP 14
EFFECT OF BACK PRESSURE UPON
TOTAL STEAM CONSUMPTION PER HR.
INITIAL PRESSURE 100 LB.
A- BACK PRESSURE 20 IN. VACUUM
B- " " 10 IN. "
C- " " 0
D- " " 5 LB.
E- " " 10 LB.
F- " " 15 LB.
TOTAL STEAM - LB. PER HR.
300
400
500
600
700
800
I.H.P.
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
F
E
D
C
B
A
24


GROUP 15
EFFECT OF BACK PRESSURE UPON
TOTAL STEAM CONSUMPTION PER HR.
INITIAL PRESSURE 80 LB.
A - BACK PRESSURE 20 IN. VACUUM
B - " " 10 IN. "
C - " " 0
D - " " 5 LB.
E - " " 10 LB.
F - " " 15 LB.
TOTAL STEAM - LB. PER HR.
300
400
500
600
700
800
I.H.P.
2
4
6
8
10
12
14
16
18
20
22
24
26
28
F
E
D
C
B
A

XI. DISCUSSION OF RESULTS.

A. Reliability of Data.

As stated before, the tests were of one hour duration. If, after starting the test, there seemed to be any change whatever in conditions, the test was prolonged beyond the one hour period and the data used for the hour during which conditions were constant. This was necessary only whenever the pressure in the steam mains got below that desired for the test. The size of the condenser was out of proportion to that of the engine, so that small pockets of water might accumulate in the condenser and come out in the form of slugs. These slugs, while ordinarily negligible, may have some effect upon the steam weighed out when the hours run only gives about 250 to 275 lb. Again, the rather long exhaust pipe might seem to give a chance for water to pocket, but tests upon this seemed to show no water trapped in the "goose neck".

At first there seemed to be a small leak in the condenser when a vacuum was used. Ordinary tests failed to disclose any leakage, but it was finally discovered. Inasmuch as the vacuum in the condenser had been kept approximately constant, the leakage was determined for this difference in pressure and was taken as a constant for these conditions. This affected only a small number of tests and retests made upon some of these proved the assumption to be of no commensurate error.

The engine was tested at various times for leakage by means of logarithmic diagrams and also a thorough examination of the engine was made. No leakage seemed to be present. All other pipes leading to the condenser or from the engine were either blanked off or were removed entirely so that all the exhaust steam, and no other, got into the condenser.

B. Results and Curves.

The water rate curves for the three initial pressures and varying back pressures and loads seem, with very few exceptions, all that can be desired. In nearly all cases where the points do not fit right on the lines retests have been made which have not differed from the points plotted. The strangest thing seems to be the curvature of the so-called Willans' lines, especially at 120 lb. initial pressure. Nothing has been found which seems to account for this. At first leakage was thought to be the cause. Tests, however, showed no leakage, and, furthermore, with constant initial and back pressures, the leakage should be almost independent of the load, thus merely raising the line without curving it.

In order to make results comparable, three things should be kept constant, initial pressure, back pressure, and ratio of expansion. Inasmuch as the purpose of this thesis is to determine the effect of initial and back pressure, it looks as though this comparison should be made upon the basis of constant ratio of expansion, and not on constant load. For this reason a third set of curves, with water rate against ratio of expansion, has been plotted.

XII. CONCLUSIONS.

No rational basis for correction has been found to exist. If the Rankine efficiency should be a basis for correction, then the steam consumption per indicated horse power should vary inversely as the heat drop during adiabatic expansion from initial to back pressure. This was tested both for conditions of constant load and constant ratio of expansion. An equation to represent this would be

$$\frac{W_1}{W_2} = \frac{i_1 - i_2}{i_3 - i_4}$$

where $i_3 - i_4$ would represent the heat drop per pound of steam when W_1 pounds of steam were being used per horse power hour, and $i_1 - i_2$ would represent the heat drop when W_2 pounds of steam were used per horse power hour. This relation does not exist for either constant load or constant ratio of expansion. This was checked by using the wet steam (or condensate) per horse power hour with the values of i determined for steam initially wet and also by using the dry steam per horse power hour (or water rate) with the values of i for steam initially dry. It was thought possible to put a constant into the equation; thus

$$\frac{W_1}{W_2} = \frac{c + (i_1 - i_2)}{c + (i_3 - i_4)}$$

Here c had a different value for every set of values substituted. A third method tried was

$$\frac{W_1}{W_2} = \left(\frac{i_1 - i_2}{i_3 - i_4}\right)^n$$

Here again n had a different value for every different set of values used.

On light loads the steam consumption per indicated horse power increases as the initial pressure increases. This is shown by curves (4) to (9) inclusive where the water rate lines invariably cross each other. This further proves the non-existence of any rational relation of water rates because the available heat drop increases with the pressure and consequently the water rate should decrease instead of increase.

The conclusion reached is that no simple rational basis for correction over any range of any consequence seems to exist and that the corrections must be made empirically from curves previously determined and standardized from a similar engine to the one under consideration.